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APR 80 M CHODOROW, B A AULD, M R BEASLEY N00014-75-C-0632

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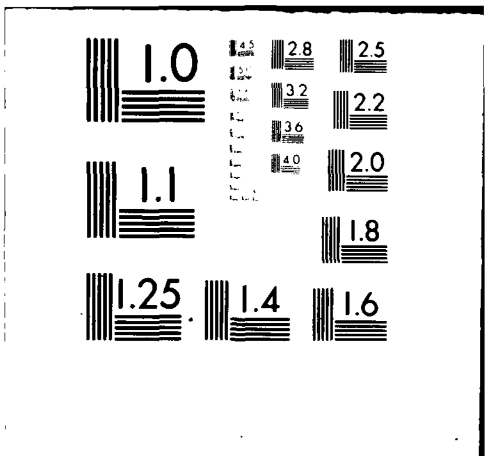

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ANNUAL PROGRESS REPORT

Joint Services Electronics Program

Contract N00014-75-C-0632

1 April 1979 through 31 March 1980

G.L. Report No. 3120

Edward L. Ginzton Laboratory
Stanford University
Stanford, CA 94305

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Submitted by Marvin Chodorow on behalf
of the faculty and staff of the
Edward L. Ginzton Laboratory

April 1980

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*A separate *Administrative Supplement* has been prepared for limited distribution which provides the *Significant Scientific Accomplishments* with other pertinent administrative data.

INTRODUCTION

This progress report covers work done under JSEP Contract N00014-75-C-0632 for approximately one year, April 1979 — April 1980. Since the report is being prepared in June 1980, there may be some imprecision in the coverage period.

Most projects are concerned with the exploration of some new concepts, using special materials and/or electronic interactions in some unique way, with some well defined objectives; for example, possible new kinds of spectroscopy using lasers to make measurements not easily done, if at all, presently, the investigation of superconducting electronic components using high T_c materials, exploration of various techniques and materials for more sophisticated and/or higher speed signal processing. In most cases, there is uncertainty as to whether the material properties, material combinations required and/or the physical performance envisaged can be achieved.

Broadly then, one can categorize most of these projects as aimed at useful and unique electronic applications by means which are still uncertain, and which will require a great deal of basic investigation of materials, processing, and technological innovation. This has been typical of the work under JSEP in this laboratory for many years where some new possibly useful concept has been conceived and then the subsequent program devoted to research to see whether this concept could actually be reduced to practice and shown to be actually a possible one given the limitation of materials, etc.

Each individual unit is described in some detail in the body of the report. However, it may be of some value to briefly list and summarize the various projects included in order to provide a birds-eye view of the whole program and its direction. There are six units.

UNIT SUMMARIES

Unit 1 — High T_c Superconducting Weak-Link Josephson Junctions and Circuits

This unit is concerned with exploring the feasibility of such circuits, the physics of the devices, the fabrication procedures, and operating characteristics. Superconducting integrated circuits are considered to be key elements for the next generation of high speed computers. It is a field which is being actively pursued elsewhere, principally IBM, but with other materials, i.e., low-T_c materials. High-T_c circuits would have very important advantages because of the ability to operate at higher temperatures, and therefore the successful development of fabrication techniques for these materials would be important. Normal photolithographic methods are not suitable because of the nature of the materials involved. Some alternatives to these methods have been developed which have led to the successful fabrication and testing of the first fully satisfactory superconducting microbridges which act as Josephson junction up to the transition temperatures of Nb (9^oK).

Unit 2 — Acoustic Surface Wave Scanning of Optical Images

The title listed here is not completely descriptive. The original program was intended to cover a broader area than is signified by the title. On the other hand, the methods which have been pursued in this unit are well suited to optical imaging, though this is not the principal thrust at present.

The unit is actually an outgrowth of a previous activity on an acoustic wave storage correlator. That device involved a piezoelectric film (zinc oxide) deposited on a silicon substrate containing a closely packed array of p-n junctions, with an additional overlying electrode on top of the zinc oxide. With that combination, a high-frequency, wide-band acoustic signal, propagating along the piezoelectric medium, could be stored as a charge pattern in the capacities associated with the individual p-n junctions. This could be read out at a later time; hence it would be a storage device or, conversely, successive, repetitive weak signals could be cumulatively stored in the charge pattern to give an enhanced sensitivity for detecting weak signals.

The current program extends this concept in two directions. First, we have demonstrated a narrow beamwidth waveguided storage correlator. Using a metal film overlay as a waveguide, we are able to increase the acoustic power densities and thereby improve dramatically the storage correlator efficiency.

Additionally, we are developing a programmable active delay line in which low-frequency signals can be read into the device by means of a charge transfer device (CTD) on the silicon substrate adjacent to the ZnO layer. Such a device can be used as a programmable tapped delay line, variable bandpass filter, adaptive filter, etc.

This device will demonstrate a marriage between very high-frequency surface wave devices and lower frequency charge transfer devices using MOS technology which would open up tremendous new possibilities in signal processing.

Unit 3 — Research on Fiber Optic Interactions with Applications to High-Speed Signal Processing

The objective of this program is to study new interactions in optical fibers, with a view to using such fibers for high-speed signal processing. That is, one would try to produce the equivalent of tapped delay lines (or possibly nonlinear interactions) as one does in electromagnetic or acoustic lines, but with data rates and bandwidths many times greater than are available with these more conventional means.

The approach would be to use very long, single mode, optical fibers, taking advantage of the low attenuation of such fibers (one to two dB per kilometer) for storing and processing very long signal trains. Even with the existing attenuation one can get storage times of many microseconds. Seventy-five microseconds, for example, would correspond to perhaps 15 to 30 dB. With the use of optical amplifiers for recirculation of the signal, one can obviously do much better. Another project being conducted here under other sponsorship is concerned with developing suitable amplifiers for other applications and would be used in this project when available. However, even in the absence of an amplifier one can still get very interesting performance. A key component required is a directional coupler suitable for single mode fibers, which can tap (or inject) a propagating signal in a fiber without breaking into the fiber. Such a coupler for fiber-to-fiber coupling has been developed with controllable coupling and very low insertion loss. This will have many applications.

Unit 4 — <u>Nonlinear Interactions of Acoustic Waves with Domains in Ferroic Materials</u>

The goal of this project is to investigate nonlinear interactions of acoustic waves with domains in ferroic, primarily ferroelastic materials, with a view to achieving better understanding of the physics and material properties involved for better conception and evaluation of potential device applications. Since the nonlinear acoustic properties of the materials of interest (gadolinium molybdate and neodymium pentaphosphate) have not previously been measured, we have been concentrating on this aspect of the problem, and have begun to grow our own material for lack of satisfactory commerical suppliers. We are also beginning to collaborate with researchers in crystal growth on a study of domains in ferroic single crystal fibers.

Unit 5 — <u>Measurement of Ultrafast Physical Phenomena</u>

In the currently very active field of picosecond spectroscopy, (i.e., the measurement of atomic and molecular phenomena occurring on picosecond time scales), measurement techniques using ultra short light pulses run into natural barriers around a few picoseconds or shorter, because of rapidly increasing difficulties with both pulse sources and measurement techniques. This work unit is aimed at bypassing these barriers by developing a novel tunable-laser-induced grating method, using tunable rather than pulsed lasers, which we can then use to measure important subpicosecond relaxation rates such as occur in semiconductors, in vibrational relaxation rates in organic molecules, and in other physical and chemical situations.

As planned in the original proposal, the primary Nd:YAG laser and three tunable dye lasers needed for this technique have now been built and operated, and are being tested and improved. The remaining optical components are now being set up to permit experiments on our first test sample — namely measurement of the subpicosecond vibrational relaxation rate in an infrared laser dye called IR 140.

In subsidiary efforts we have also developed and published a useful new technique for pulse-stretching and pulse-shaping in the type of Q-switched laser we are using; and we have published two theoretical papers on four-wave mixing and on its application to dynamic holography and interferometry. The type of nonlinear grating interaction between three or more optical beams that we propose to use in our subpicosecond spectroscopy is essentially similar in fundamental principles to the nonlinear wave interactions that occur in so-called "four-wave mixing" and "phase conjugation," which are also topics of large current interest. Thus, our contributions to these topics arose naturally as a by-product of our primary objectives in this work unit.

Unit 6 — A VUV and Soft X-Ray Light Source

The purpose of this project is to develop a tunable, VUV light source of high intensity and narrow bandwidth by anti-Stokes scattering of light (produced by a laser pump), from the metastable state at 584 Å in a helium discharge. This kind of scattering has already been previously demonstrated and used as part of this program, but the intent here was to try to find a discharge geometry and method of producing the discharge which would optimize the anti-Stokes radiation relative to the background radiation at 584 Å. We have found several such geometries which seem to work well, and also developed a photodetector with a high work function cathode to discriminate the anti-Stokes light from scattered visible laser radiation. With a suitable laser pump we have been able to produce radiation at around 540 Å, five times brighter than the background radiation. With a suitable pump, probably a Nd:YAG system, for a tunable dye laser, it is anticipated that one can produce high peak energy from the dye laser to use as a source to generate anti-Stokes light over the entire tuning range of available dye lasers (50,000 cm^{-1}). Such a tunable VUV source will have many applications in certain important kinds of spectroscopy, photolithography, etc.

Our intention at the moment is to use this source for some very high resolution VUV spectroscopy of importance to us, without the limitation of traditional VUV apparatus: the lack of bright sources and the low efficiency resolution of VUV spectroscopy.

JSEP Sponsored*

Publications and Papers

Bing-Hui Yeh, "SH Wave Propagation on Corrugated Surfaces," Internal Memrandum (July 1979).

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G.S. Kino, "Nondestructive Evaluation," Science 206, 173-180 (12 October 1979).

R.B. van Dover, R.E. Howard, and M.R. Beasley, "Fabrication and Characterization of S-N-S Planar Microbridges," IEEE Trans. on Magnetics MAG-15, 574-577 (1 January 1979).

G.S. Kino, "Zinc Oxide on Silicon Acoustoelectric Devices," Reprint from Ultrasonics Symposium Proceedings, 900-910 (September 1979).

J.B. Green and B.T. Khuri-Yakub, "A 100 μm Beamwidth ZnO on Si Convolver," Reprint from Ultrasonics Symposium Proceedings, 911-914 (September 1979).

B.A. Auld and B.H. Yeh, "Theory of Surface Skimming SH Wave Guidance by a Corrugated Surface," Reprint from Ultrasonics Symposium Proceedings, 786-790 (September 1979).

B.A. Auld, M. Fejer, and H. Kunkel, "Interaction of Acoustic Waves with Ferroelectric and Ferroelastic Domain Walls," presented at the Electronics Division, Fall Meeting, The American Ceramic Society, September 1979, Williamsburg, VA; to be published.

R. Trebino and A.E. Siegman, "Phase-Conjugate Reflection at Arbitrary Angles," Optics Commun. 32, 1-4 (January 1980).

Wolfram E. Schmid, "Pulse Stretching in a Q-Switched Nd:YAG Laser," Preprint (November 1979).

A.E. Siegman, "Dynamic Interferometry and Differential Holography of Irregular Phase Objects Using Phase Conjugate Reflection," Optics Commun. 31, 257-258 (December 1979).

R.A. Bergh, G. Kotler, and H.J. Shaw, "Single Mode Fiber Optic Directional Coupler," Electronics Letters 16, 260-261 (27 March 1980).

R.B. van Dover, A. de Lozanne, R.E. Howard, W.L. McLean, and M.R. Beasley, "Refractory Superconductor S-N-S Microbridges," to be published in the 1 September 1980 issue of Journal of Applied Physics.

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*Totally or partially

Unit 1

HIGH-T_c SUPERCONDUCTING WEAK-LINK JOSEPHSON JUNCTIONS AND CIRCUITS

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A. Research Plan and Objectives

The underlying, long term objective of this program is to explore the feasibility of high-T_c and/or hard Josephson junction superconducting thin-film circuits; to establish the relevant physics, fabrication procedures, and operating characteristics of such devices; and hopefully to lay the ground work for a superconducting integrated circuit technology based on these materials. This objective requires the development of practical high-T_c and/or hard Josephson junctions and also the passive circuit elements necessary for a complete circuit technology. Success in this program would lead to devices capable of operating at substantially higher temperatures (~ 10-15 K) and/or to more rugged circuits resistant to damage due to thermal cycling, handling, and hostile field environments.

Toward this general objective we have been developing superconducting weak-link (i.e., non-tunneling) Josephson junctions using refractory and high-T_c superconducting materials and by necessity thin-film deposition, microlithography, and processing technologies suitable for such materials. Specifically we have been concentrating our efforts on the A15-type superconductors, specifically Nb_3Sn ($T_c \simeq 18$ K) with related work on elemental Nb($T_c = 9$ K) in order to more easily test some of our fabrication techniques.

From the theoretical point of view[1.1] when considering refractory and high-T_c superconducting materials the most attractive type of weak-link Josephson junctions appear to be planar SNS (superconductor/normal metal/superconductor) or SSemiS (superconductor/semiconductor/superconductor) bridges. Although it must be noted that granular superconducting weak links have recently shown interesting performance.[1.2] The theory of such devices has not yet been presented, however. In this program we are focusing on SNS bridges. These bridges are like the usual microbridges but where the bridge region itself is a normal metal while the banks are superconductors. The rationale for such devices is that by making the bridge from a normal metal (e.g., Cu, Au, or Ag) one can circumvent the extremely small (< 100 Å) bridge dimensions theoretically required in a totally superconducting high-T_c bridge to obtain ideal Josephson behavior. In such SNS bridges the dimensions need only be submicron and ideal Josephson behavior should be suitable over the entire temperature range $0 < T < T_c$.

To achieve such structures in practice we have been using electron-beam evaporation to make suitable thin-film bilayers (e.g., Nb_3Sn or Nb on top of Cu or vice versa) out of which the desired submicron planar SNS (e.g., $Nb_3Sn/Cu/Nb_3Sn$) bridges are formed by projection photolithography and suitable differential etching procedures. The fabrication procedures are then appropriately modified in light of the observed electrical properties of the junctions. More specifically the problem

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[1.1] K.K. Likharev, Rev. of Mod. Phys. 51, 102 (1979).

[1.2] See for example, J.H. Claassen, Appl. Phys. Lett. 36, 771 (1980).

is to fabricate a short ($\leq$ 1 μm) normal metal bridge connecting two superconducting banks while insuring good contact at the S/N interfaces and not degrading the superconductivity (e.g., reducing T_c) of the banks through damage in the fabrication process. At the same time we have been developing theoretical models for such devices based on the Usadel, Ginzburg-Landau and Time-Dependent-Ginzburg-Landau Theories of superconductivity.

B. Progress and Accomplishments

In the early phases of this project we explored various techniques for actually forming the desired submicron bridge structures and mastered the necessary projection photolithography techniques. This work demonstrated the feasibility of the planar SNS bridge concept and indicated that devices with attractive practical characteristics could be fabricated in principle from the high-T_c, hard superconductors, although the processing requirements were demanding.[1.3] In particular, wet etching and/or conventional ion milling were not suitable because of the poor spatial resolution of the former and the damage produced in the superconductors of interest for the latter.

Subsequently we have explored alternative processing techniques and have found that plasma (or reactive ion etching) is eminently well-suited for application to these types of materials and devices. It affords delicate material removal, selective etching, and high spatial resolution. Through trial and error we have now developed plasma etching procedures

[1.3] R.B. van Dover, R.E. Howard, and M.R. Beasley, IEEE Trans. on Magnetics MAG-15, 574-577 (1979).

capable of routinely making submicron Nb/Cu/Nb and Nb/Au/Nb SNS planar bridges with outstanding spatial definition. Preliminary results on Nb_3Sn are also very encouraging.

As we reported last time the electrical performance of these devices unfortunately did not reliably match their good physical definition. This suggested problems associated with insufficiently clean S/N interfaces between the superconducting and normal materials where they join in the banks of the bridge. Happily the simplest and easiest improvements, along with the identification of an apparently hostile wet etch used to strip photoresist, has led to dramatic improvements both in the electrical characteristics of our bridges and in our device yield. Use of Au as the normal metal also appears to be the optimum choice.

Now that good Nb/Au/Nb devices are routinely available we have undertaken a more detailed study of their device characteristics and compared them with available theoretical models. The results are quite encouraging. In particular we have investigated the temperature dependence of the critical current $I_c(T)$ (and hence the I_cR-product which is an important device parameter) and the I-V characteristics. Experimentally we find that these devices work as Josephson junctions over the entire temperature range $0 < T < T_c$ and yield I_cR products (up to 0.5 mV) superior to any previous weak-link type Josephson junctions. Joule heating and normal hot spot formation (which can be a serious problem with devices formed from refractory materials because of their poor thermal conductivity) is found to be vastly reduced in these devices because of the good thermal properties of the Au. Device resistances have been obtained as large as $0.5\,\Omega$, which is a bit low but satisfactory for many important applications.

Smaller devices, perhaps $0.1\ \mu \times 0.1\ \mu$, are expected to yield larger device resistances. Finally we find that the magnitude and temperature dependence of the critical current can be accounted for using the Likharev-Usadel approach providing suitable modifications are made to account for the actual geometry of the S/N and bridge bank interfaces compared to the idealized theory. Furthermore, near T_c, where it is expected to apply, the I-V curves are in good agreement with our numerical calculations based on the time-dependent-Ginzburg-Landau theory. Thus not only do the devices now appear to be operating well, the device modeling also appears to be under control. A paper describing these recent results has been submitted for publication. With these encouraging results we are aggressively moving ahead on more refined study of the electrical device characteristics and also in attempting to make such bridges with the higher-T_c materials.

C. Publications (under this JSEP Program)

1. R.B. van Dover, R.E. Howard, and M.R. Beasley, "Fabrication and Characterization of S-N-S Planar Microbridges," IEEE Trans. on Magnetics MAG-15, 574 (1979).

2. R.B. van Dover, A. De Lozanne, R.E. Howard, W.L. McLean, and M.R. Beasley, "Refractory Superconductor S-N-S Microbridges," accepted for publication in the 1 September 1980 issue of Applied Physics Letters.

Unit 2

ACOUSTIC SURFACE WAVE SCANNING OF OPTICAL IMAGES

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(J. B. Green)

A. Introduction

At the present time our work is being focused on developing acoustic surface wave devices in which we can utilize the interaction which occurs between surface acoustic waves and the charge carriers in a semiconductor. All of our device designs involve the use of piezoelectric zinc oxide which is rf sputtered onto a silicon substrate. Due to the piezoelectric nature of the zinc oxide, electric fields are generated by the acoustic surface waves propagating along the device. These electric fields penetrate into the silicon substrate and interact with the charge carriers near the silicon surface.

Our work now centers around two types of devices:

(1) An acoustic surface wave waveguide storage correlator; and

(2) A programmable active delay line in which signals can be read into the device by means of a charge transfer device (CTD) on the silicon substrate underneath or adjacent to the ZnO layer. After programming the device in this way, we could then use the device in a wide variety of signal processing applications including, but in no way restricted to, adaptive and inverse filtering. This device is an excellent example of the uses

to which sophisticated LSI technology can be put in sophisticated real-time applications involving real-time analog and digital signal processing.

B. Progress and Accomplishments

We feel that a basic building block for surface wave correlators and programmable delay lines is a narrow, waveguided acoustic surface wave device. Narrow beamwidth devices possess an inherent advantage over wider beamwidth devices since the acoustic power density in the propagation path is proportionally higher, resulting in more efficient device operation. Additionally, narrow beamwidth devices offer the advantage of high fabrication densities, which offers the potential of constructing two dimensional devices for imaging and signal processing applications. The device which we have recently investigated is a $\Delta v/v$ waveguided monolithic ZnO on Si storage correlator. A device such as this offers the advantage of high efficiency and straightforward fabrication utilizing the techniques well familiar to those involved in standard IC processing.

The waveguide storage correlator, illustrated in Fig. 1, employs a piezoelectric ZnO layer deposited on Si. Interdigital transducers are used at each end of the device to inject or receive acoustic surface wave signals. In the central region, a row of p-n diodes is fabricated in the silicon underneath the acoustic beam path and metal films (top plate electrode and waveguide metallizations) are deposited on top of the zinc oxide. Since the acoustic surface wave velocity is slightly lowered in the presence of the gold film, the surface wave

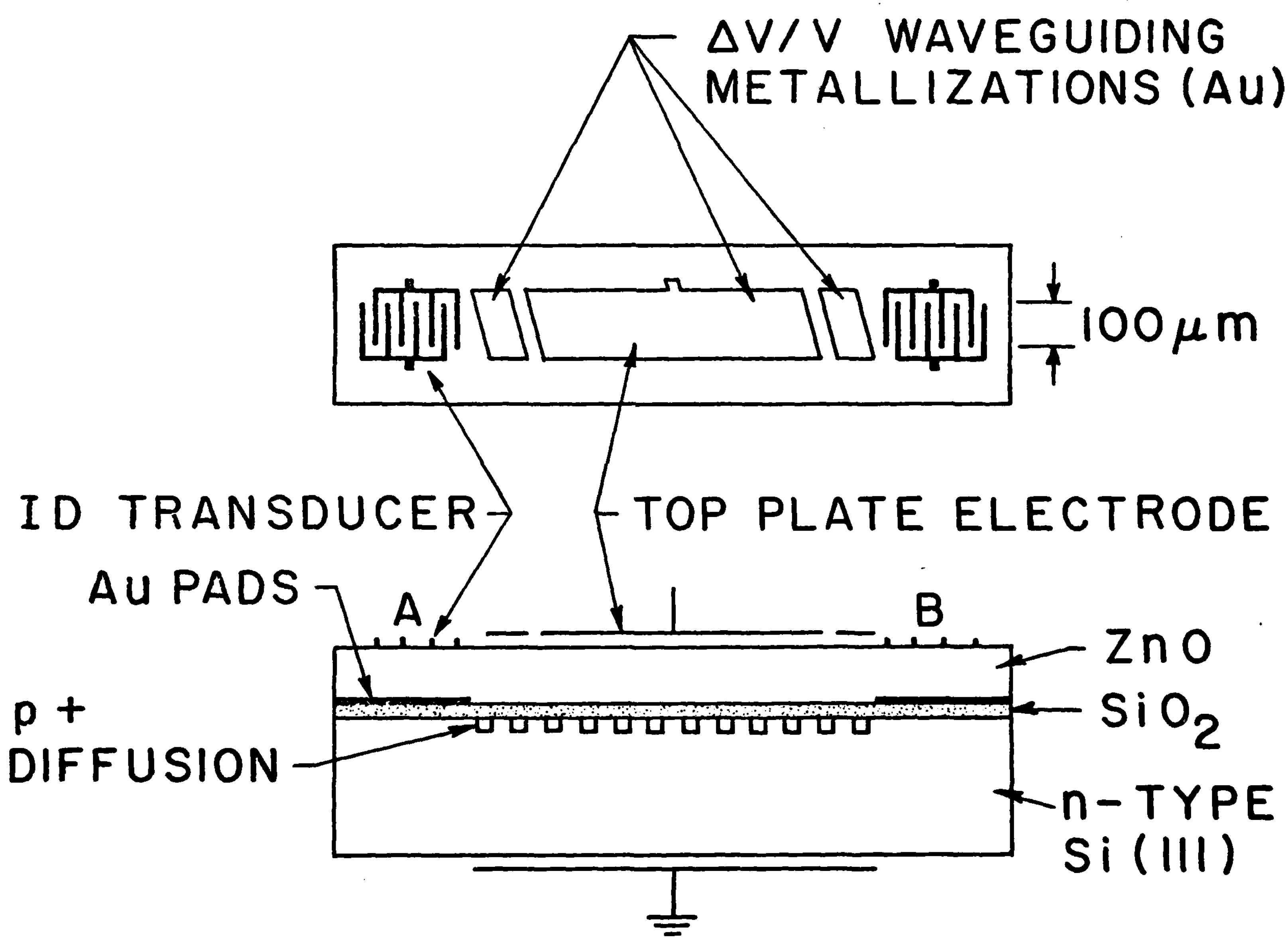

ΔV/V WAVEGUIDING
METALLIZATIONS (Au)
100μm
ID TRANSDUCER
TOP PLATE ELECTRODE
Au PADS
A
B
ZnO
SiO2
p +
DIFFUSION
n-TYPE
Si (III)

FIGURE 1

tends to propagate only in the region defined by the gold films; therefore the waveguiding effect is achieved.

In order to understand the operation of this device, consider what happens when a short pulse of voltage V is applied to the top plate. The pulse "turns on" each diode so that the capacity between the top plate and an individual diode becomes charged to a potential close to V. After the pulse is turned off, the capacity remains charged; clearly then, the device can store an analog signal. If at the same time an acoustic surface wave signal is passing under the plate when the diode is turned on, the signal stored in the capacitor consists of the sum of the acoustic surface wave signal and the applied pulse. A spatial pattern of charge corresponding to the surface wave signal is stored along the length of the device. At a later time, a further "reading" pulse applied to the "top plate" turns on the diodes once more, but the potential at which they turn on depends on the signal stored in the capacitors. Thus, a spatially varying signal is excited along the length of the device which, in turn, excites acoustic surface waves which can be received on either interdigital transducer. If a more general form of reading signal is applied, the correlation of this signal with the original signal read into the device is obtained as an output from one transducer, and the convolution of the two signals is obtained from the other transducer.

The device itself has been operated in several different modes, but basically it functions as a highly flexible signal processing device which correlates signals either read into it at the same time or read into it at different times.

The results obtained from a waveguided correlator of this type have been extremely encouraging and showed a correlation efficiency $F_T^{corr} = -53$ dBm where F_T^{corr} is defined as

$$F_T^{corr} \equiv 10 \log (P_{e3}/P_{e1}P_{e2})$$

P_{e1}, P_{e2}, and P_{e3} are, respectively, the input acoustic power, the read-out power applied to the top-plate electrode, and the output power, all expressed in mW . This terminal correlation efficiency $F_T^{corr} = -53$ dBm is 13 dB better than that reported for any other ZnO on Si storage correlator. Figure 2 shows the correlation output of two rectangular input pulses. A paper on this device has been submitted to Applied Physics Letters.

At the present time we are attempting to further improve the bandwidth and efficiency of the waveguided correlator by development of a new interdigital transducer design. This involves using a curved transducer approximately 1 mm wide to focus an acoustic surface wave beam at one end of the waveguide. It has been necessary to develop a new theory for the design of a curved transducer which takes account of focusing in an anisotropic medium. We now have this basic design theory in hand and intend to construct one of these devices in the near future.

Programmable ASW-CTD Storage Device

The programmable delay line concept involves constructing an adaptable monolithic SAW filter which can be programmed from an external source. To do this, we intend to combine the features of the acoustic surface wave storage correlator and charge transfer device

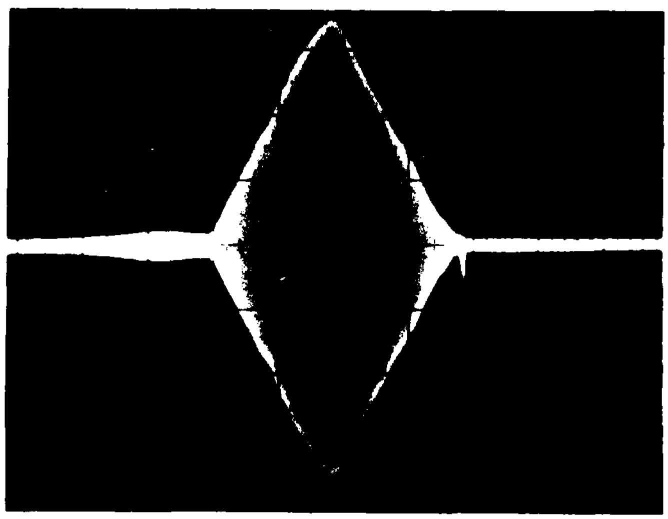


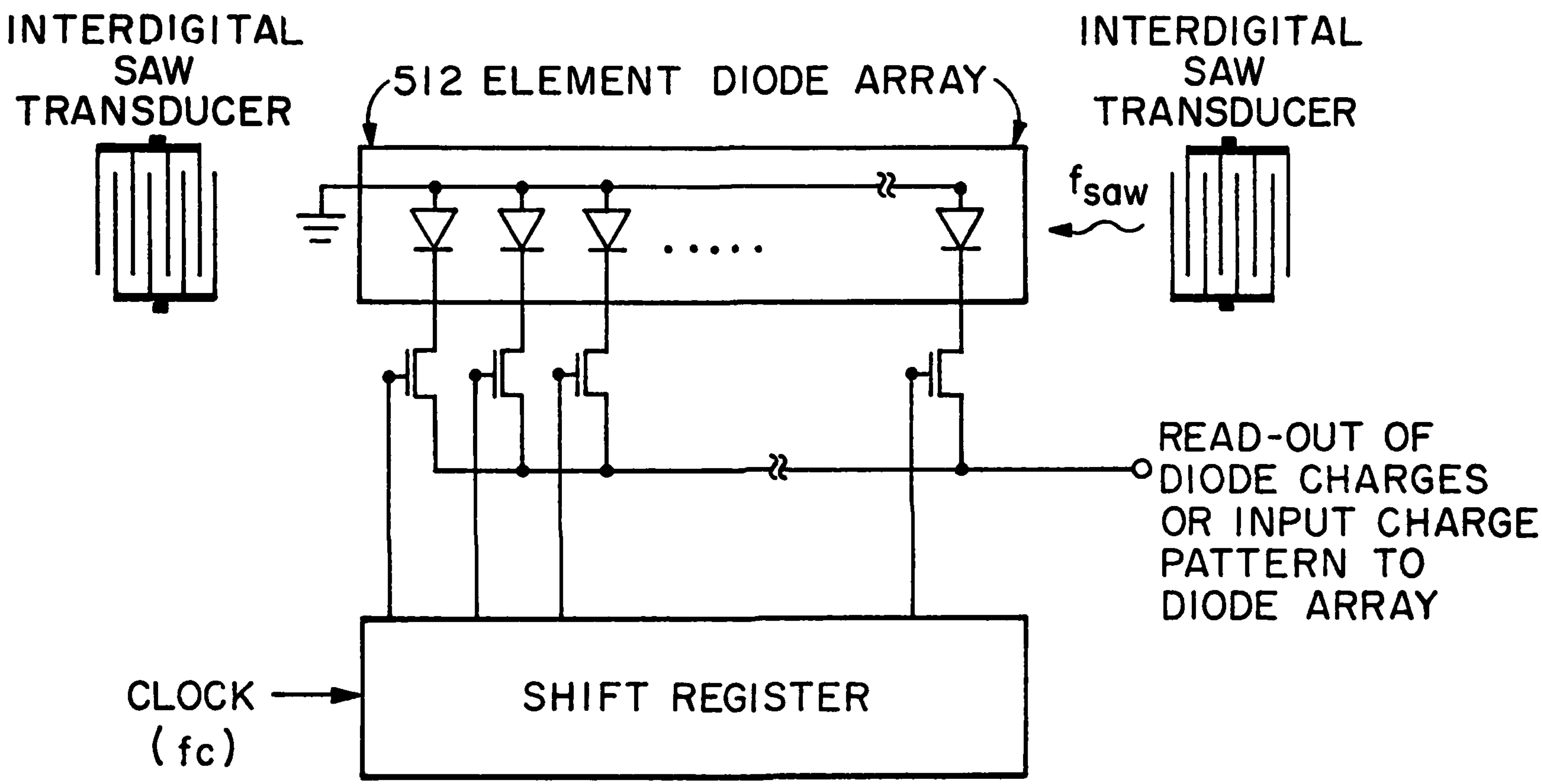
FIGURE 2

(CTD) on one silicon substrate and therefore avoid the pitfalls of hybrid technology which limit the number of taps which can be realistically employed.

The basic principles of operation of this device follows directly from that of the storage correlator. Figure 3 shows a simplified view of the device. We see here that it is very similar to the storage correlator except for the important difference that each diode is connected to a MOSFET, the drains of all the individual MOSFETS being connected to a common input-output line. The gates of the MOSFETS themselves are controlled by a shift register. We see that this device employs far more sophisticated semiconductor techniques than just the diffusion of simple diodes. It is capable of processing high-frequency signals (from the surface acoustic waves), while controlling the processing with relative low frequency signals (by way of the shift register/multiplexer arrangement). It is also possible to use such a configuration as a system for reading in and processing a signal at high speed using surface acoustic waves and reading out the processed signal at low speeds using the CTD portion of the device.

At the present time, photo-sensitive devices have been developed which read out the charge produced by light incident on a row of diodes from an illuminating source, such as one line of a TV image. Thus, the basic devices exist which can switch from an input-output line to any one of a row of diodes.

One such commercial device which we are presently using is made by Reticon Corporation. This device (RL 512 S) is a solid state line scanner in which a series of FET switches are used to connect individual diodes to an input-output line. These switches are addressed



$f_{saw} >> fc$

SCHEMATIC OF SAW-CTD DEVICE

FIGURE 3

one after the other by a controlling signal inserted into a tapped shift register with one tap per switch. Thus with the Reticon device we possess the capability of switching to any one of 512 diodes and ultimately to any one of a row of 1024 diodes. The beauty of using this sophisticated device lies in the fact that in order to convert it to an adaptable SAW filter, we need, in principle, only to deposit a zinc oxide layer with a metal film laid on top of it, and associated surface wave transducers, on top of the diode array. Thus we are able to read a signal into (or out of) the diodes at the surface wave frequency (64 MHz) but also address the diodes slowly at the frequency of the CTD multiplexer (less than 2 MHz).

As one simple example, we might read in a coded signal through the CTD into the diodes. This forms a set of taps with variable weighting on the acoustic surface wave delay line. Therefore, if a signal is read into the acoustic surface wave delay line and read out of the top plate on the high-frequency terminal, the device acts as a programmable tapped delay line. Thus, we should be able to make programmable filters, variable delay devices, etc. by reading a low-frequency analog signal into the device. As this low-frequency analog signal can in turn be controlled from a shift register or RAM through a D-to-A converter, we now have the possibility of constructing a range of coded surface wave devices whose codes are obtainable from a digital memory.

A major difficulty in using the Reticon device has occurred in our ability to deposit high-quality zinc oxide over the diode array. During the last year our zinc oxide technology has progressed to the point where we can reliably deposit extremely high-quality zinc oxide over thermally grown silicon dioxide, but we have experienced considerable difficulty in performing the zinc oxide deposition on top of the chemical vapor deposited (CVD) silicon dioxide as is found over the diode array on the Reticon device. This is due to the more irregular structure of the CVD silicon dioxide as compared to thermally grown silicon dioxide. In order to surmount this problem, we attempted to deposit our own sputtered silicon dioxide layer on top of Reticon's CVD layer. This proved unsuccessful due to adhesion problems between the CVD SiO_2 and the sputtered layer of SiO_2. We therefore directed our attention to removing the CVD layer of SiO_2 until all that was left over the diodes was the thermal oxide. By monitoring our progress with both an optical microscope and a scanning electron microscope, after many tries we were able to develop an etching technique that utilizes a selective oxide etch to remove only the CVD oxide while leaving the underneath thermal SiO_2. Using this technique, we have now been able to deposit reasonably high quality zinc oxide over the diodes.

We have been using three techniques to monitor the quality of the deposited ZnO:

(1) Reflection electron diffraction (RED),

(2) Interdigital transducer input impedance, and

(3) Acoustic surface wave attenuation using liquid wedge surface wave transducers.

Whereas the ZnO deposited over the CVD SiO_2 showed RED patterns consisting of rings (indicating poor nonoriented ZnO), the zinc oxide that we have deposited over diodes that have had their CVD oxide etched off has shown sharp dots in conjunction with the rings. The sharp dots are an indication of highly oriented zinc oxide. The remaining ring pattern is most likely due to the diode steps which are very sharp edges where the zinc oxide becomes very nonoriented. It remains to be determined whether these diode steps will severely degrade device performance.

By measuring the input impedance of an interdigital transducer, we are able to determine the degree to which the zinc oxide is oriented. This measurement on some of our early devices showed no surface acoustic wave resonance. We therefore chose to use liquid wedge surface wave transducers in order to check out our subsequent devices. These transducers provide a known surface wave to the device and enable us to measure zinc oxide quality (in regards to acoustic wave attenuation) and also enable us to test basic device operation. Using these wedge transducers we have been able to demonstrate a terminal-to-terminal insertion loss of only 24 dB while propagating the surface wave along the device. This compares with previous measurements of over 70 dB loss.

Unfortunately, when we attempted to fabricate an operating device using the wedge transducers, two further difficulties arose:

(1) The process of ZnO deposition damaged the silicon MOSFETs and shift registers so that the Reticon device was no longer operational, and

(2) We were not able to line up the wedge transducers accurately with the diodes.

After masking the operational parts of the Reticon device so that only the diodes were exposed furing the ZnO sputtering operation, we were able to make a partially operational device.

Based on these results, we feel very confident that we will have a completely operational device in a short period of time. We are now constructing a full device using interdigital transducers.

We believe that these concepts are merely the first of a wide range of devices which could be constructed with entirely new configurations and system architecture if the necessary LSI and VLSI silicon technology were available. We have described here, for instance, only a device controlled from a shift register input; a still more flexible valuable time delay signal processing device could be made if the control were directly made from a RAM input rather than the shift register. Yet other possibilities arise by using amplifiers in the acoustic analog system rather than passive diodes. Thus, with a sophisticated VLSI technology available, a new signal processing technique can be devised to carry out analog or digital signal processing in real time at relatively high frequencies (in the UHF range). We are currently discussing procedures for making these devices in the new Stanford Center for Integrated Systems.

C. Publications and Papers Citing JSEP Sponsorship

1. G.S. Kino and C.S. DeSilets, "Design of Slotted Transducer Arrays with Matched Backings," Ultrasonic Imaging 1, 189-209 (July 1979).
2. G.S. Kino, "Nondestructive Evaluation," invited paper, Science 206, 173-180 (12 October 1979).
3. G.S. Kino, "Zinc Oxide on Silicon Acoustoelectric Devices," invited paper, Proc. Ultrasonic Symposium 900-914 (September 1979).
4. J.B. Green and B.T. Khuri-Yakub, "A 100 μm Beamwidth ZnO on Si Convolver," Proc. Ultrasonics Symposium 911-914 (September 1979).

Unit 3

RESEARCH ON FIBER OPTIC INTERACTIONS WITH APPLICATION TO HIGH SPEED SIGNAL PROCESSING

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A. Introduction

Systems for high speed signal processing using optical fibers are being studied under this project. The first step involves the development of addressable memory elements in the form of recirculating optical delay lines and tapped delay lines, and the development of key fiber optic components required for these delay lines. A tapped delay line is a basic component for performing a wide variety of signal processing operations, such as convolution, correlation, Fourier transformation and the various processing and filtering functions which derive from them.

The data rates and sample sizes in conventional systems such as DSP, CCD, or SAW, for signal processing operations of the above kinds, are much lower than are potentially achievable with optical systems. Modern optical fibers have extremely attractive properties for use in delay lines for these purposes. They can be coiled with very large numbers of turns to provide a long propagation path occupying small volume and having very high information capacity and processing speed.

We have studied the operation of recirculating delay lines both theoretically and experimentally, and have carried this operation as far as is feasible without an integrated optical coupler for the fiber for introducing and extracting signals. In the meantime, we have developed a successful integrated coupler with which to carry the work further, and which is expected to have a major impact in this field.

B. Recirculating Delay Lines

We are studying recirculating memories using optical fibers, to determine their potential for long-time volatile storage of very broadband electronic signals modulated onto optical beams. Systems of this kind (Fig. 3.1) have been developed using closed loops of coaxial cable or waveguide as recirculating delay lines for the storage of signals modulated onto microwave rf carriers. Such systems are used for temporary storage and retrieval of broadband microwave signals in ECM applications. Analogous systems using surface acoustic wave delay lines at UHF frequencies have been developed,[3.1] and have been applied here earlier, under a JSEP project, to signal processing operations.[3.2] Systems using bulk acoustic wave delay lines have also been developed as transient memory stores for digital signal processing.[3.3] In our present approach, the microwave coax or waveguide delay line is replaced with a fiber optic waveguide, with prospects for much larger bandwidth and delay time per circulation.

When the present program began, no optical counterparts of the directional couplers of Fig. 3.1 existed, and a hybrid version of these couplers, using bulk optical components external to the fiber for injecting, recirculating and extracting signals, was developed under the

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[3.1] L. A. Coldren and H. J. Shaw, Proc. IEEE 64, 5, 598-609 (May 1976).

[3.2] C. M. Fortunko and H. J. Shaw, Trans. IEEE SU-21, 1, 40 (Jan. 1974).

[3.3] E. K. Sittig and J. F. Smits, Bell System Tech. Journal, 659 (March 1969).

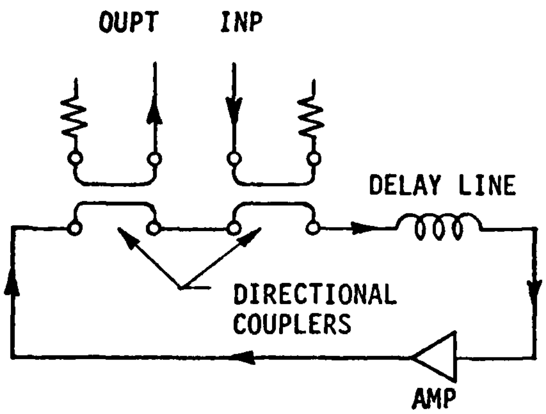

FIG. 3.1--Schematic of recirculating delay line.

program. With this approach, successful operation of a system using a coil of single-mode fiber of 600 meter length, having 5 μsec delay per circulation was reported.[3.4] More recently we have studied the operation in more detail both theoretically and experimentally.

Successful operation of the recirculating delay line requires the simultaneous solution of two alignment problems, to achieve (1) efficient injection of light into the loop from an external laser, and (2) efficient reentry of same light into the loop after each extraction. Because these two alignments are mutually interactive, cut and try alignment procedures are not successful, and two step-by-step protocols were developed, one of which involves the use of a second "alignment" laser. Computer simulations of the system were used in developing these procedures and specifying the component requirements. Using this process it was possible to show that optical pulses (pulse length approximately 2 μsec) can be recirculated many times around a single-mode fiber coil, a total of 5 circulations being demonstrated in these experiments.

The number of recirculations was limited by the essentially irreducible alignment and dissipative losses associated with the bulk optical components. In large measure these problems result from the fact that this portion of the optical circuit is not a single-mode system. This work demonstrated the need for a low-loss single-mode coupler. A coupler of this kind would eliminate the problems described above. The need for such a coupler is not unique to signal processing systems; it is one of

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[3.4] Annual Progress Report, JSEP Contract N00014-75-C-0632, Edward L. Ginzton Laboratory, Stanford University (July 1979).

the most urgently needed components for fiber optic systems in general, including communication systems and sensor systems.

C. Fiber-Fiber Directional Couplers

The development of new media for wave propagation often lead to new systems for communication or control, as was true, for example, of wave-guides for rf electromagnetic waves, electron beams for space charge waves, ferrite media for magnetoelastic waves, and crystal media for surface acoustic waves. In all cases, the basic wave propagation characteristics were studied using, at first, inefficient means for exciting the waves, but the demonstration of useful prototype devices did not take place until an efficient coupler was available for introducing waves from an external generator and extracting signals to an external load. Although the exceptional low-loss and low-dispersion characteristics of wave propagation in single mode optical fibers has been demonstrated, there has not been a satisfactory and efficient coupler for multiport, single-mode fiber optic systems. Under the present program during the past year we have demonstrated a coupler which has excellent performance[3.5] and which we believe meets the requirements for fiber optic system development.

A standard single-mode optical fiber consists essentially of two co-axial dielectric cylinders, an inner core and an outer cladding. These have slightly different optical indices such that an optical wave which is guided by the core has evanescent fields which extend outside the core, into the cladding, but decay to negligible values at the outer diameter of

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[3.5] R. A. Bergh, G. Kotler, and H. J. Shaw, Electronics Letters 16, 7, 260-261 (21 March 1980).

the cladding. Thus two such fibers, if brought into contact, have negligible cross-coupling. The object of the work on integrated fiber-fiber directional couplers is to modify the claddings in a local region in such a way that useful cross-coupling can occur, so that a desired fraction of the energy propagating in one fiber can be transferred to the other. A key requirement of such a coupler is that it introduce only very small dissipative loss. This is a significant requirement because geometrical changes in the fiber structure are capable of scattering light energy into propagating modes in the cladding and in space outside the fiber, and this energy is lost from the system. Other important requirements are mechanical ruggedness, low backscatter, high directivity, polarization insensitivity, and accurate control of the fiber-fiber coupling coefficient.

We have been working on several versions of integrated fiber-fiber directional couplers, and have succeeded in reducing one approach to practice. This device is shown schematically in Fig. 3.2. It consists of two nominally identical halves, each of which consists of a fiber bonded into a slot in a quartz substrate block. The trajectory of the fiber within the block follows a controlled radius of curvature (convex toward the substrate surface) in the sagittal plane. The substrate and fiber are ground and polished optically flat, and to a depth which places the final substrate surface within a few microns of the fiber core. Placing two such units in contact allows the fringing evanescent fields of the two fibers to cross-couple in the desired way. A film of index matching oil is introduced at the interface and, for experimental use, and the assembled coupler is placed in a fixture where micrometers are used to

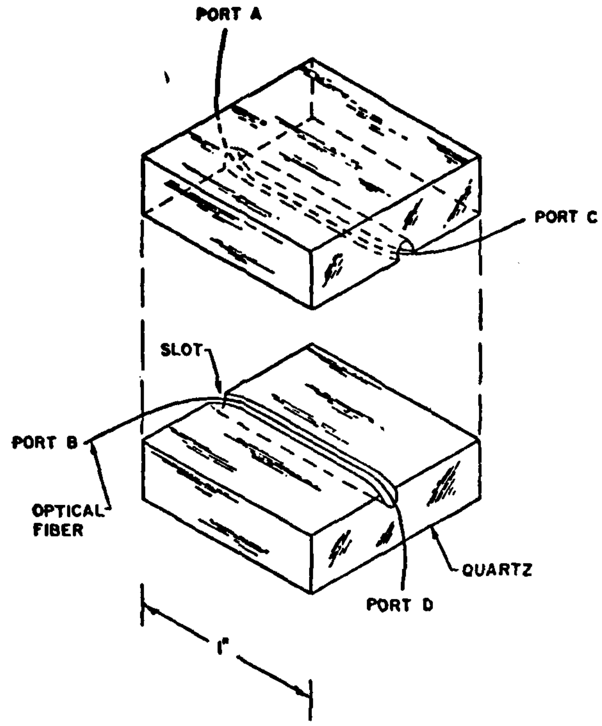

FIG. 3.2--Two slotted quartz blocks in which fibers have been bonded, illustrating the components of a coupler.

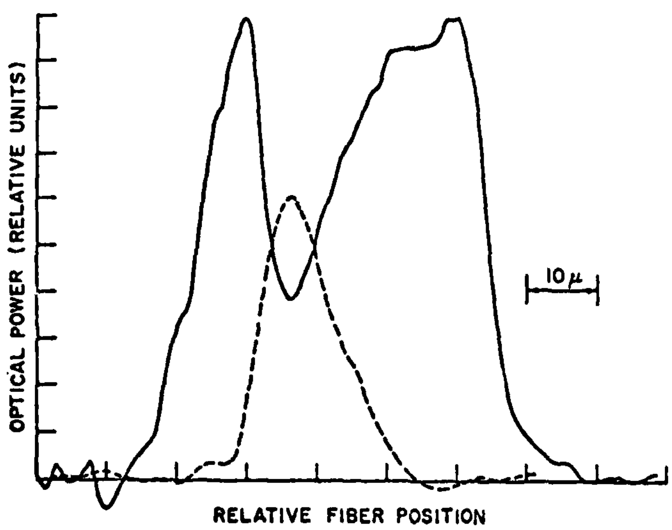

FIG. 3.3--Optical power vs. relative fiber displacement.

slide the blocks relative to each other in the one rotational and two linear degrees of freedom which are available. The techniques involved above are straightforward, but a great deal of care and attention to detail were involved, and a large amount of optical lapping skill and art, in achieving a first measurable indication of coupling, and then optimizing the coupling. This can be attributed to the small core diameter (in the range of 4 μ to 10 μ for typical single mode fibers) and to the difficulties of locating the boundaries of the invisible core with micron accuracy using essentially dead-reackoning techniques.

From Fig. 3.2 the device is seen to be a close analog to a microwave tapered long-slot directional coupler. In use, optical power fed into one of the four ports, e.g., port A in the figure, exits at ports C and D in a controlled ratio, while negligible power emerges from port B. Conversely, power fed into port C is transferred partially to port B, and similarly for the introduction of power into the other ports.

In operation the couplers show quite classical directional coupler behavior and follow theoretical predictions well. An example of the behavior of the coupler is given in Fig. 3.3, which shows the optical power emerging from ports C (solid curve) and D (dashed curve) as a function of lateral displacement of the two substrates perpendicular to the planes of the fibers, with power fed in at port A. The power cross-coupled to port D is seen to have a single maximum, which occurs when the two fibers lie in the same plane, and to fall off on either side, and can be set to any desired value between the maximum of the curve (85% of input power in the present case) and zero. At the same time, the power emerging from the straight-through port C contains a dip, which represents power removed from the input fiber and transferred to the coupler fiber. It will also be seen that the power emerging from the straight-through fiber drops sharply to essentially zero when the fibers are translated further apart, outside of the cross-coupling region. This is due to direct radiation from the core of the straight-through fiber into the cladding of the coupled fiber.

The fiber used for the coupler in Fig. 3.3 has core diameter 9 μ, numerical aperture 0.07, V parameter 1.8, and the radius of curvature of the fiber trajectory in the coupler is 1 meter. The maximum coupling coefficient is 85% and the throughput loss is less than 10% at a wavelength of 1.15 μ (where the fiber is single-mode). The directivity and polarization sensitivity, measured at .633 μ where the fiber supports more than one mode, are greater than 60 dB and less than 10% respectively. A theory developed by McIntyre and Snyder[3.6] for the coupling between two two-dimensional idealized fiber cores has been useful in this project.

An important characteristic of this coupler is mechanical ruggedness. The strength of a single-mode fiber rests in the thick cladding, and leaving approximately half of the original cladding intact as in the present case allows the fiber to be completely protected by embedding in a rigid substrate. A different approach in which most of the cladding is removed (by chemical etching) has been reported.[3.7]

[3.6] P. D. McIntyre and A. W. Synder, J. Opt. Soc. Am. 63. 1518 (1973).

[3.7] S. K. Sheem and T. G. Giallorenzi, Optics Letters 4, 29 (1969).

D. Future Plans

Directional couplers of the type described above can be spliced directly into a recirculating delay line circuit in the manner shown in Fig. 3.1. A new delay line will be set up using a longer (1 km) fiber which will have greatly increased capability for multiple recirculations resulting from much lower recirculation losses, as a result of: (1) fiber designed for operation at 1.06 μm wavelength (a shift from the present .633 μm wavelength), allowing much lower fiber insertion loss, (2) freedom from previous fiber coupling losses, because the system is automatically aligned as assembled, as a result of the single mode property of the new couplers, (3) large reduction of recirculation loss because of low throughput losses of the new couplers, (4) number of recirculations readily optimized because of adjustability of coupling coefficient of the new couplers. Components for this system (additional directional couplers, Nd:YAG source laser, external laser pulser, etc.) are under construction or procurement at this time. A fiber optic amplifier being developed under another contract will be available for use in this program also at a future date, as indicated in Fig. 3.1. In the meantime the system will be operated passively. Further development of fiber directional couplers has been transferred to industrial support, and all future work under the present contract will concentrate on delay line development and signal processing techniques.

E. Publications under JSEP Program

R.A. Bergh, G. Kotler, and H.J. Shaw, Electronics Letters 16, 260-261 (21 March 1980).

Unit 4

NONLINEAR INTERACTIONS OF ACOUSTIC WAVES WITH DOMAINS IN FERROIC MATERIALS

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A. Introduction

Ferroic materials (ferromagnetic, ferroelectric and ferroelastic) have the unique property of exhibiting switchable configurational states with distinct macroscopic material properties. These states are not only switchable but also have a latching property, or memory. That is to say, once the material is switched it remains in the switched state until further addressed by an electrical or mechanical signal. Furthermore, different regions of a single specimen of ferroic material may be in different configurational states. These regions of distinctly different configurational states, called domains exhibit distinct physical properties and the boundaries between domains, or domain walls, are therefore surfaces of abrupt change in material properties. The existence of switchable and latching boundaries of this nature provide a basis for a variety of optical and acoustical devices such as diffraction and phase matching gratings, directional couplers, filters and memory stores. The goal of this project is to study the nonlinear interaction of acoustic waves with domains (primarily in ferroelastics and ferroelectric-ferroelastics) with a view of gaining a better understanding of the physics involved and then evaluating the potential of such materials for new device applications.

The general research plan focuses on (1) the nonlinear acoustic properties of ferroic materials, particularly the influence of domain walls on these nonlinearities, (2) the influence of domain wall structure on acoustic parametric processes and harmonic generation and, (3) the interaction between a domain wall and the static forces generated by nonlinear elastic "rectification" of an acoustic wave. We are concentrating our efforts on two materials — gadolinium molybdate (GMO), a ferroelectric-ferroelastic, and neodymium penta- or ultraphosphate (NUP), a pure ferroelastic.[4.1,4.2] The latter material, which is currently arousing great interest with regard to miniature infrared laser applications but is not commercially available, is being furnished to us in a cooperative effort by W. Zwicker of Philips Laboratories. This same material is also being studied optically by A. E. Siegman of this laboratory using the pulsed transient grating technique developed by him, an activity of a somewhat similar nature to that being performed under Unit 5 of this current program. Another related activity at Stanford is being developed by the Crystal Technology Group in the Stanford Center for Materials Research. This concerns a new technique for growing thin single crystal fibers of ferroelectric and ferroelastic materials and studying the properties of domains in these fibers. We are currently continuing to interact closely with this group.

[4.1] H.P. Weber, B.C. Tofield, and P.F. Liao, Phys. Rev. B11, 1152 (1975).

[4.2] J.P. Budin, A. Milatos-Roufas, N.D. Chien, and G. LeRoux, J. Appl. Phys. 46, 2867 (1975).

With regard to potential device applications of the materials and phenomena under study, these all involve the use of periodic arrays of gratings, created and aligned by either the nonlinear acoustic method referred to above or electrical poling techniques above the Curie temperature. Specifically of interest are acousto-optic diffraction gratings for signal processing, phase matching for collinear phase matched optical harmonic generation and gratings for distributed feedback lasers. The latter aspect of the potential is of particular interest in connection with the miniature NUP lasers noted above.

B. Progress and Accomplishments

Our experiments on domain wall motion induced by a nonlinearly generated static elastic stress (Item 3 in the Introduction) have not yet met with success. There exist three possible reasons for this:

(1) The threshold stress (or strain) required for wall motion is higher than expected.

(2) The nonlinearly generated rectified elastic field is of smaller magnitude or different spatial distribution than anticipated.

(3) The interaction of the walls with the nonlinear acoustic field is not of the nature projected.

Our response to these questions will be discussed below but, first, a brief review of the experiments will be given. The idea of the experiment was to construct a high Q face shear GMO resonator with a resonant frequency in the half megahertz range. A domain wall was to be injected into the resonator. Driving the resonator with a voltage on the order of 10 - 100 volts was expected to produce sufficiently large rectified strains to cause a macroscopic translation of the domain wall. As of our last report we had succeeded in producing the necessary high Q resonator.

In order to excite the resonator one must have a 10 - 100 V supply whose frequency is equal to that of the resonator to one part in Q. Since the resonant frequency shifts both with temperature and driving voltage, it was necessary to build a high voltage oscillator whose frequency is controlled by the GMO resonator. We designed and built such an oscillator. This oscillator and improved resonator design obviate the need for the coupled PZT-GMO oscillators mentioned in last year's report.

It is, however, not sufficient to have a high Q resonator. The threshold for domain motion must also be low. This can be measured by determining the minimum DC voltage sufficient to cause wall motion. The threshold electric field and stress field are linearly proportional, so measuring one is as good as measuring the other. This threshold field was found to be quite sensitive both to the condition of the edges of the crystal, e.g., the presence of any nicks, scratches or other imperfections, and defect density in the bulk crystal. The processing of a crystal into a resonator was found to introduce both these difficulties. Prevention of edge damage necessitated special handling procedures throughout the process, particularly during electroding and the thermal-compression bonding of leads to the electrodes. In addition, it was found that mechanically poling the crystal often led to an unsatisfactory edge condition. We then developed an electrical poling technique which obviated the necessity of any mechanical contact with the edges of the crystal. Elimination of bulk defects was accomplished by annealing the resonator at 400°C for four hours. It was found that it was necessary to anneal the resonator after processing, as the cutting and polishing introduce defects into the crystal.

All the above procedures are now understood, but unfortunately in mastering them our supply of GMO was exhausted. We presently have one GMO resonator, which has a moderately high, but useable, threshold. At this point we should mention the progress of our efforts to obtain more crystals for our research. During the past year this supply question has become the most serious obstacle to progress in our research; we have assigned high priority to the acquisition of more GMO. The only commercial supplier of GMO is Hitachi Magnetics. In August of 1979 we ordered a $3 \times 3 \times 1$ cm boule of optical quality GMO. The boule delivered was found to contain numerous ~ 20 μm diameter inclusions of the alpha phase. These inclusions render the material useless for ferroelastic studies, as the domain walls pin and wall motion is difficult or impossible. A replacement boule obtained from Hitachi in January, 1980 had the same problem as the first. It was indicated that no better material was obtainable through Hitachi. We thus entered into an agreement with Stanford's Center for Materials Research to grow high quality GMO. The have been in contact with L. H. Brixner at Dupont,[4.3] experienced in the growth of GMO and expect the first boule to be available within a month or two. We have also been addressing our material

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[4.3] L. H. Brixner, J. Crystal Growth 18, 297-302 (1973).

supply problem by switching part of our effort to neodymium pentaphosphate (NUP). This material is ferroelastic but not ferroelectric or piezoelectric. The threshold stress for domain motion is two orders of magnitude lower than that of GMO, making it promising for wall control applications. We have obtained a $1 \times 2 \times 2$ cm boule of NUP from W. Zwicker of Philips Laboratories. These sources of supply will allow us to study nonlinear acoustic interactions in traveling wave structures at higher frequencies, as projected in our proposal.

Three possible reasons for the lack of domain wall motion in the GMO resonator experiments were listed above and are discussed in more detail in the following.

(1) As already discussed, the threshold for wall motion in a uniform field can easily be measured. For our resonator this threshold was sufficiently low that wall motion was expected. However, the acoustic fields in a plate resonator are of necessity nonuniform because free edge conditions must be met on all six boundaries. The threshold for motion in an inhomogeneous field is less well known. This could be investigated by applying DC voltages to crystals with various partial electrode patterns. We have designed such an experiment, but lack the GMO to construct the necessary pieces pending arrival of the material to be grown by the Center for Materials Research.

(2) Our understanding of the nonlinear acoustic fields is progressing both theoretically and experimentally. The information relevant to the problem is the magnitude and spatial distribution of the rectified strain in the face shear resonator. This problem can be solved iteratively. First a set of solutions to the linear problem

must be obtained. The nonlinear stress terms are then calculated using this linear solution. Finally, these nonlinear terms are treated as sources in the linear equation, to calculate the response at 2ω and the rectified response. To follow this prescription, it is necessary to have both a set of solutions to the linear problem, and at least partial knowledge of the nonlinear coefficients.

Most literature calculations of nonlinear resonators concern thickness shear devices where a quasi-plane wave approximation to the linear solution is appropriate. For the face shear geometry that we use this approximation is not valid. We have done a calculation based on first order Mindlin theory for anisotropic plates that yields resonant frequencies and approximate field distributions for the coupled extensional-flexure-shear vibrations.[4.4] The resonant frequencies calculated are in good agreement with those observed for the GMO resonators.

The other necessary input for the nonlinear calculation are the nonlinear coefficients. Several experimental methods for the measurement of these coefficients exist. The most accurate method involves the measurement of the derivatives of acoustic wave velocity with respect to various uniaxial and hydrostatic stresses. Unfortunately this method requires rather elaborate equipment unavailable to us. The proposal noted our desire to collaborate with Prof. Breazeale of the University of Tennessee on this type of measurement,[4.5] but we have been unable to provide him with the necessary crystals. This possibility will be

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[4.4] P. Lee, J. Appl. Phys. 42, 4139 (1971).

[4.5] M. Breazeale, J. Appl. Phys. 36, 3486 (1965).

re-examined when our new material becomes available.

A less accurate but probably sufficient method involves traveling wave second harmonic generation, as mentioned in our last report. We have solved the equations of motion for second harmonic generation in non-pure mode directions and designed appropriate $LiNbO_3$ transducers to launch the necessary driving wave. The experiment will be performed as soon as a sufficiently large piece of GMO is obtained.

An order of magnitude figure for the relevant nonlinear coefficient can be obtained from the amplitude dependence of the resonant frequency of the face shear GMO resonator. Using an oversimplified plane wave theory, a value of $c_{6666}/c_{66} = 400$ was obtained for GMO. This is a fairly small value; for quartz $c_{6666}/c_{66} \approx 2000$. The result for GMO is a crude estimate; if it holds up in our more careful measurements and c_{666}/c_{66} is similarly small, the estimated rectified strain would be reduced by a factor of one hundred. In recent conversations with J.J. Gagnepain, an expert in the field of acoustic nonlinearities,[4.6] we have proposed a novel means for obtaining nonlinear coefficients by measuring the second harmonic in a resonator with properly designed split electrodes. We are currently processing a quartz resonator in the necessary configuration to test the method. Since the third order nonlinear elastic constants of quartz are known, the accuracy of the method can be checked. If validated, this method will be of value not only to our measurements on ferroelastic materials, but also to nonlinear acoustics in general.

[4.6] J.J. Gagnepain, "Nonlinear Effects in Piezoelectric Quartz Crystals," in Physical Acoustics, Vol. XVI, W.P. Mason and R.N. Thurston, eds. (New York, Academic Press, 1975), pp 245-288.

(3) We are not emphasizing study of the third point, errors in the calculation of the interaction of the domain wall with the acoustic wave, since an understanding of the first two points is prerequisite to the third. It is worth mentioning, however, that in connection with our measurements of the amplitude-frequency effect, we observed an anomalously high damping, with an apparent threshold behavior, when a domain was present at certain positions in the resonator. This phenomenon could be related to a linear response of the domain wall to the acoustic field. If such is in fact the case, it would have an impact on our experiment. We have designed a laser scattering experiment to measure the extent of linear wall response.

It was noted above that we have begun this year our study of ferroelastic-acoustic effects in neodymium ultraphosphate (NUP). We are currently processing the Philips boule for a travelling wave second harmonic generation measurement of the nonlinear coefficient. Resonator construction is complicated by the nonpiezoelectric nature of NUP. In order to design a coupled resonator out of a piezoelectric material and NUP to efficiently excite a particular NUP mode, it is necessary to know the frequency of that mode; but, as NUP is nonpiezoelectric, there is no simple way to determine its resonant frequencies. We are using our recently developed analysis of plate modes (discussed in the section on GMO) to facilitate the design process, and have a resonator currently under construction. The elastic constants of lanthanum ultraphosphate[4.7] are being used for the design calculations,

[4.7] G. Errandonea and P. Bastie, Ferroelectrics 21, 571 (1978).

for lack of elastic constant data for neodymium ultraphosphate (NUP). We have already performed several experiments on empirically fabricated PZT-NUP composite resonators and have observed resonance in the NUP, but mode identification awaits completion of our properly designed resonators.

Since NUP is not ferroelectric, electric poling and domain injection are not possible. We have developed a mechanical jig that can be used to pole and inject domains in NUP with minimal edge damage.

Two experiments mentioned in last year's report led to inconclusive results. The experimental test of Kumada's domain injection method[4.8] produced large strains and cracking in the sample piece. The method will be further tested with the new GMO supply and additionally in NUP.

The nonlinear acoustic microscopy to investigate strain distributions around domain walls proved to be of too low resolution to reveal any interesting structure. A higher resolution, linear acoustic microscopy investigation is underway with another Stanford group.

C. Publications and Papers

1. Bing-Hui Yeh, "SH Wave Propagation on Corrugated Surfaces," Internal Memorandum (July 1979).

2. B.A. Auld and B.H. Yeh, "Theory of Surface Skimming SH Wave Guidance by a Corrugated Surface," Ultrasonics Symposium Proceedings 786-790 (September 1979).

3. B.A. Auld, M. Fejer, and H. Kunkel, "Interaction of Acoustic Waves with Ferroelectric and Ferroelastic Domain Walls," partially sponsored by JSEP, presented at the Fall Meeting of American Ceramic Society, Sept. 16-19, 1979; submitted to the Society Journal.

[4.8] A. Kumada, IEEE Trans. ED-20, 866 (1973).

Unit 5

MEASUREMENTS OF ULTRAFAST PHYSICAL PHENOMENA

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I. INTRODUCTION

The general objective of this group is to develop and apply new laser methods for the measurement of ultrafast physical, chemical and biological processes - an area which has come to be known as picosecond spectroscopy. The particular objective of this project is to demonstrate and make use of a novel technique we recently proposed[1] which should permit the measurement of subpicosecond physical phenomena using a tunable laser-induced grating method.

Over the past few years our group has successfully measured several ultrafast processes (partially under JSEP support) using picosecond laser pulses in a transient laser-induced grating technique.[2-7] In this pulsed technique two picosecond pulses from the same laser arrive at an experimental sample at the same time, but from two different directions, creating a transient interference pattern and producing a transient hologram or grating of excited states in the sample. The diffraction of

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[5.1] A.E. Siegman, "Proposed Measurement of Subpicosecond Excited-State Dynamics Using a Tunable-Laser-Induced Grating," Appl. Phys. Lett. 30, 21-23 (15 January 1977).

[5.2] D.W. Phillion, D.J. Kuizenga, and A.E. Siegman, "Rotational Diffusion and Triplet State Processes in Dye Laser Solutions," J. Chem. Phys. 61, 3828 (1 November 1974).

a separate variable-delay probing pulse by this grating is then measured as a function of the delay between excitation and probe pulses. By observing the diffracted intensity versus delay time in this manner, we have measured both fast relaxation times and orientational rotation times (10^{-8} to 10^{-11} sec) in organic dye molecules,[2,3] and also fast transport or diffusion processes of excited electronic states in organic molecular crystals.[4,5] Very interesting microwave acoustooptic effects have also been observed.[6]

Many important physical processes have characteristic times in the subpicosecond range. In the <u>tunable</u> laser-induced grating technique being developed under this project the excitation beams are cw (or long-pulse) lasers which have an adjustable frequency difference f_d between them, with f_d in the 0.1 - 10 cm^{-1} range. These two beams produce a moving interference pattern, whose fringes sweep through the sample at the frequency f_d. The excited-state pattern induced in the sample then follows or does not follow these moving fringes, depending upon whether the excited state response time τ is short or long compared

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[5.3] Donald W. Phillion, Dirk J. Kuizenga, and A.E. Siegman, "Subnanosecond Relaxation Time Measurements Using a Transient Induced Grating Method," Appl. Phys. Lett. <u>27</u>, 85 (15 July 1975).

[5.4] D.D. Dlott, M.D. Fayer, J.R. Sakcedo, and A.E. Siegman, "Energy Transport in Molecular Solids: Application of the Picosecond Transient Grating Technique," in <u>Picosecond Phenomena</u>, edited by C.V. Shank, E.P. Ippen, and S.L. Shapiro, Springer-Verlag, Berlin, 1978, 240-243.

[5.5] J.R. Salcedo, A.E. Siegman, D.D. Dlott, and M.D. Fayer, "Dynamics of Energy Transport in Molecular Crystals: The Picosecond Transient Grating Method," Phys. Rev. Lett. <u>41</u>, 131-134 (10 July 1978).

[5.6] J.R. Salcedo and A.E. Siegman, "Laser Induced Photoacoustic Grating Effects in Molecular Crystals," IEEE J. Quant. Electr. <u>QE-15</u>, 250-256 (April 1979).

to the frequency f_d. In particular, for $f_d > 1/\tau$ the excited states will not be able to follow the moving fringes. The grating pattern will then be washed out, and the probe diffraction will disappear. The "break frequency" in a plot of diffracted probe intensity versus difference frequency f_d between the excitation beams should yield the time constant τ. For simple cases the relation between lifetime and break frequency is

$$f_d(\mathrm{cm}^{-1})\tau(\mathrm{psec}) \approx 5.3 \quad .$$

Thus, a time constant of 0.1 psec (100 femtoseconds) corresponds to 50 cm^{-1} of tuning, which is easily achieved with modern dye lasers. This technique should become most useful just where conventional picosecond or subpicosecond pulse techniques become impossibly difficult.

[5.7] A.E. Siegman, "Grating Spectroscopy," Invited paper, Conference on Dynamical Processes of Excited States in Solids, Madison, Wisconsin, June 18-20, 1979.

II. PROGRESS TO DATE: THEORY

We are planning to apply the tunable laser-induced grating method eventually to a wide variety of physical systems, including:

-- rotational and fluorescent lifetimes in organic dye solutions and in large molecular complexes.

-- excited-state and carrier lifetimes in semiconductors.

-- exciton diffusion processes in one-dimensional organic crystals.

-- vibrational relaxation processes in liquids.

-- lifetime measurements in dyes used for laser Q-switches mode-lockers, and optical Kerr cells.

We have reviewed the literature on subpicosecond phenomena[8] in these systems. Of particular interest to us initially are organic dye solutions and semiconductors. We thus plan to do our initial experiments with a dye solution and then focus on obtaining important results relevant to semiconductor physics.

Because the diffraction efficiency in these tunable-laser-induced grating experiments will be low, we undertook a careful study to determine the experimental parameters that will yield maximum diffracted signal intensity for a given sample material. The excitation and probe wavelengths, sample concentration (if liquid), sample length, and the angle between the excitation beams are among the parameters that are at the experimenter's discretion. Certain constraints exist, however, limiting

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[5.8] Erich P. Ippen and Charles V. Shank, "Sub-Picosecond Spectroscopy," Physics Today, 41-47 (May 1978).

the choice of these variables, i.e., imperfect temporal coherence of the excitation beams places an upper limit on the sample cell length, and saturation effects and sample damage limit the beam intensities. Also many variables are tightly coupled to each other: the absorption cross-section is explicitly a function of light wavelength.

We have developed a design procedure that will, for a given sample material, maximize the diffracted signal intensity. Interestingly, this procedure calls for the use of excitation beam wavelengths at which the material to be studied has a very low absorption cross-section. Absorption is obtained by relatively high sample concentration and long interaction length. The cross-section for absorption by excited states at the probe wavelength should however be large. Theoretical diffraction efficiencies approaching unity may then be obtained if the appropriate wavelengths of laser light are available.

With this procedure in mind, we will perform our initial measurements on the organic dye molecule IR-140, an infrared laser dye which lases in the wavelength range 805 nm to 1015 nm[9]. It possesses a vibrational relaxation time most likely in the subpicosecond range. It has also been shown to exhibit strong excited state absorption at 532 nm[10] while absorbing only weakly - in the ground state - at visible wavelengths where our excitation dye lasers operate.

[5.9] Exciton Chemical Co., Inc., Laser Dyes

[5.10] C. David Decker, "Excited State Absorption and Laser Emission from Infrared Laser Dyes Optically Pumped at 532 nm," Appl. Phys. Lett. 27(11), 607-609 (December 1975).

III. PROGRESS TO DATE: EXPERIMENT

The allowable light intensity incident on the sample is limited by both saturation effects and material damage and will likely be lower than that which is available from our planned laser setup. In addition, pulse lengths must be long compared to certain sample material relaxation times, which can be as long as ten to twenty nanoseconds in some materials. As a result, we undertook in the past year to design and build a Nd: YAG laser capable of producing "stretched" Q-switched pulses as much as ten times longer than the normal Q-switched pulse length of 20-50 nsec. No simple and efficient method to do this was known previously. Through the efforts of a visiting scholar (Dr. Wolfram Schmid of the Max Planck Institute at Garching) this pulse-stretching has been accomplished using a fast high-voltage feedback circuit driving a programmed Pockels-cell Q-switch in the laser.[11] Kilovolt feedback signals with nanosecond time constants were obtained with a fast ceramic planar microwave diode.

We have also augmented our Nd: YAG laser with a 1200 watt average power pulse-forming network with a 1/4" diameter rod, so that it is now capable of producing up to 400 mJ of energy per pulse in an unstable resonator configuration at a repetition rate of 10 pps. It is also possible to run at lower pulse energies and much higher repetition rates.

5.11 Wolfram Schmid, "Pulse-stretching in a Q-switched Nd:YAG laser," in press.

Three dye lasers, employing a design developed at Rice University which uses a reflective cassegrainian beam expander and a grating in the Littrow configuration at its blaze angle,[12] have been built (Fig. 5.1) and are now being tested. These lasers will provide the two excitation beams and probe beam for the tunable grating experiment. These lasers are now complete and operating. Tests of their wavelength tuning properties and beam quality should be completed in the near future, after which our first tunable grating experiments will begin.

5.12
E.J. Beiting and K.A. Smith, "An On-Axis Reflective Beam Expander for Pulsed Dye Laser Cavities," Optics Comm. 28(3), 355-357 (March 1979); E.J. Beiting, "The Use of a Concave Grating in Pulsed Dye Laser Cavities," Optics Comm. 29(2), 209-212 (May 1979).

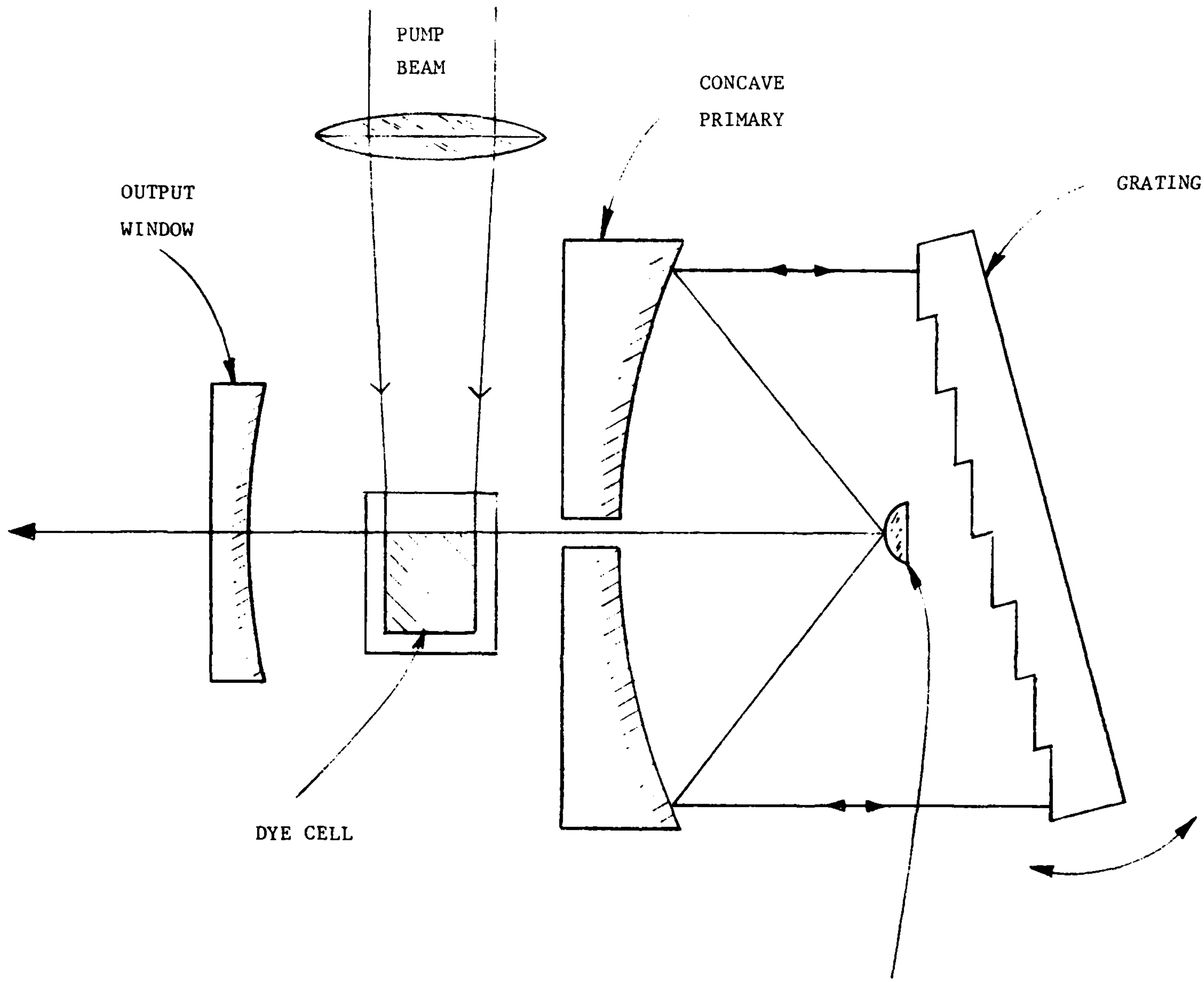

FIGURE 5.1: Design of the tunable dye lasers for the tunable transient grating experiment

IV. OTHER THEORETICAL WORK: PHASE-CONJUGATE REFLECTION AND FOUR-WAVE MIXING

For the transient grating and tunable transient grating projects, we have been studying the diffraction of a laser beam by a laser-induced material grating, a process which can also be considered as a type of four-wave mixing. The knowledge obtained in this endeavor has been very helpful in understanding the phenomenon of phase-conjugate reflection by four-wave mixing in which - for the noncollinear geometry - laser beam diffraction by a laser-induced material grating occurs. Two publications have resulted.

We have calculated[13] the spatial and angular dependence of the reflection from a phase-conjugate mirror using degenerate four-wave mixing pumped by collumated gaussian TEM_{00} pump waves. Our analysis is valid for all cell lengths and arbitrary incidence angles and beam profiles of the incident signal wave, neglecting depletion and diffraction effects. We have found that for small incidence angles or thin samples the four-wave mixer behaves as a "gaussian reflectivity phase-conjugate mirror," while for large incidence angles and thick samples, reflection nonuniformity in the plane of the k-vectors disappears.

Because reflection by a phase-conjugate mirror acts to cancel out aberrations in optical beams caused by propagation through a stationary distorting medium, this reflection can be used to perform measurements on small rapid changes in a phase object which occur in the time required

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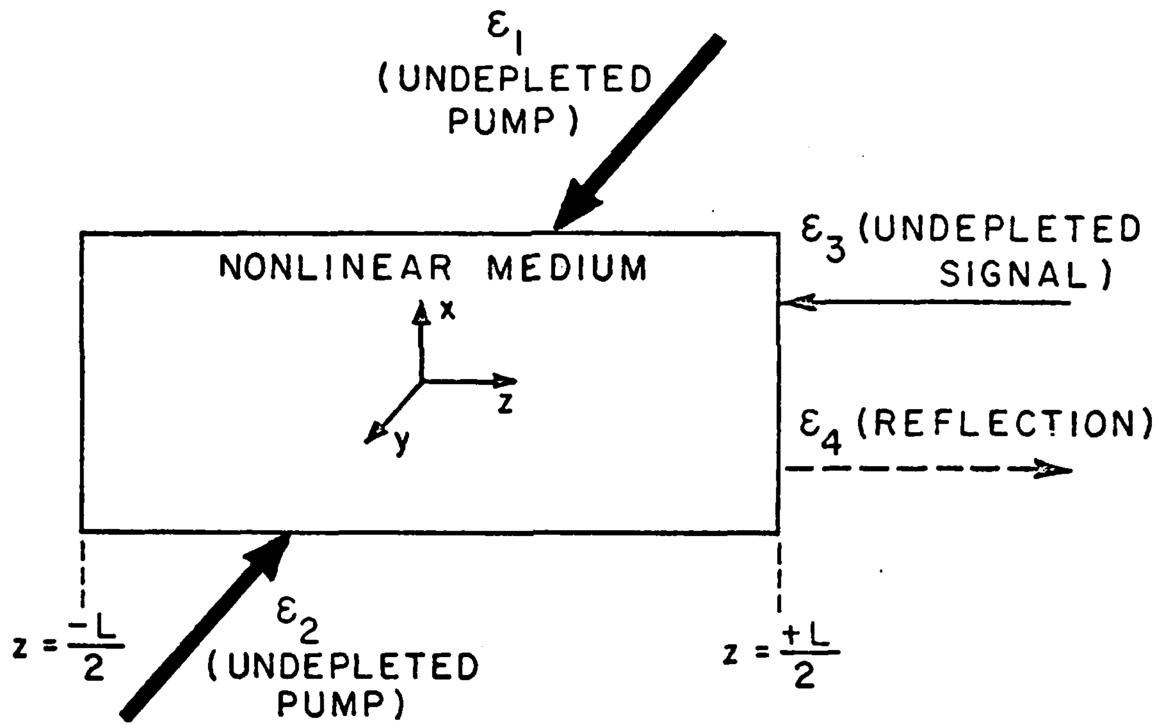
[5.13] Rick Trebino and A.E. Siegman, "Phase-conjugate Reflection at Arbitrary Angles Using TEM_{00} Pump Beams," Optics Comm. 32(1), 1-4 (January 1980).

for the beam to propagate from the object to the mirror and back to the object.[14] Thus high-speed dynamic and/or differential holography on highly irregular transparent phase objects is possible: the phase irregularities in the phase-conjugate reflection caused by motion in the object can be made visible by interfering the reflection with a reference beam.

This general principle would appear to have interesting potential applications for observing very high speed phenomena, including perhaps laser damage, laser fusion targets, and self-focusing effects in transparent media. It accomplishes much the same function as double-pulse holographic interferometry, but for high-speed changes. The acoustic nondestructive testing applications of the basic concept may also be interesting.

Figures 5.2 and 5.3 illustrate the coordinate system involved in the off-axis four-wave mixing process, and the type of experimental geometry in which such four-wave mixing and phase conjugation could be used to achieve time-resolved differential holography and interferometry.

[5.14] A.E. Siegman, "Dynamic Interferometry and Differential Holography of Irregular Phase Objects Using Phase-conjugate Reflection," Optics comm. 31(3), 257-258 (December 1979).



<u>FIGURE 5.2</u> : Four-wave mixing geometry. $\mathcal{E}_1$ and $\mathcal{E}_2$ are undepleted pump beams, $\mathcal{E}_3$ is undepleted signal beam, and $\mathcal{E}_4$ is the phase-conjugate reflection of $\mathcal{E}_3$.

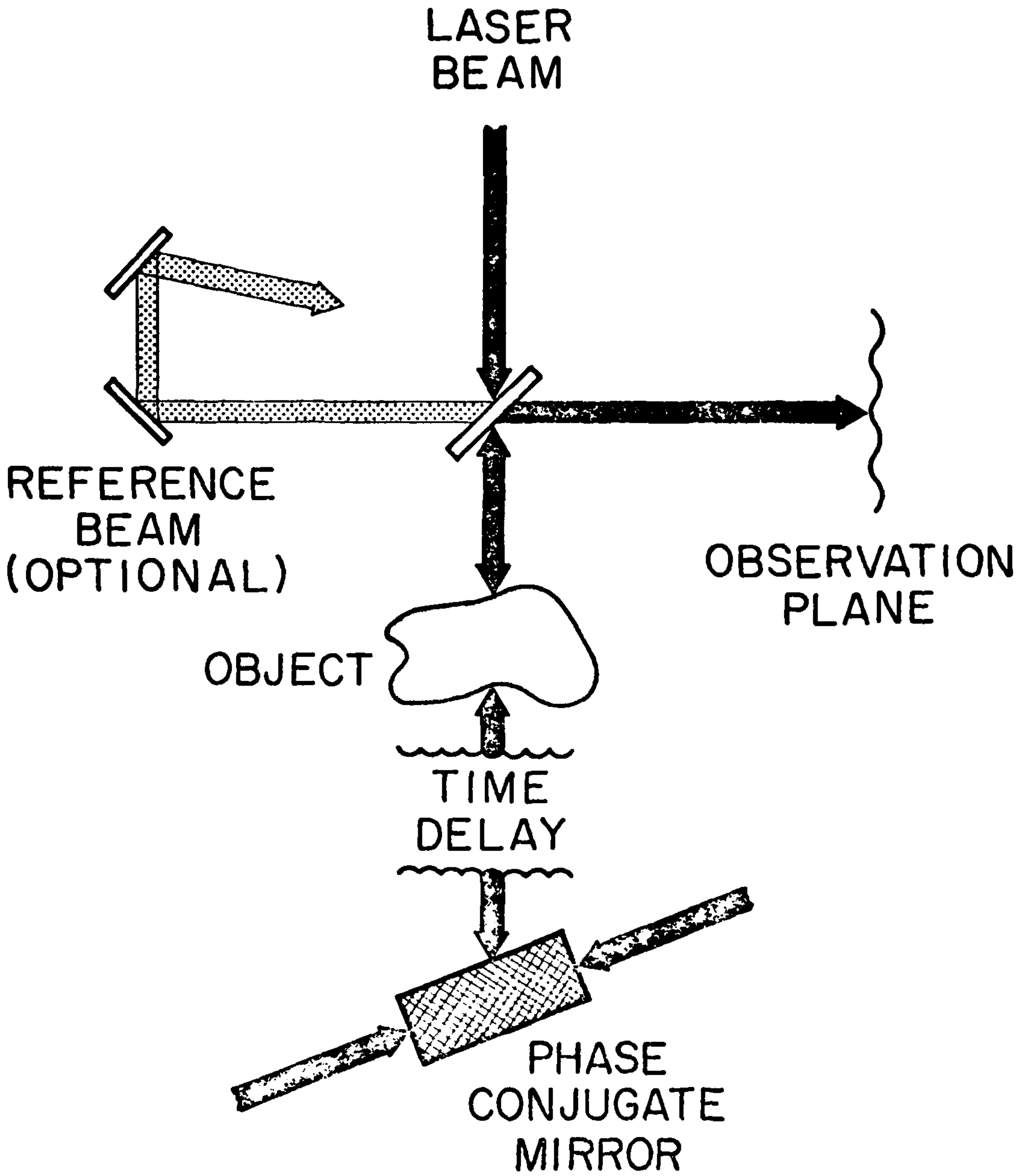


FIGURE 5.3: General experiment arrangement for dynamic interferometry and/or differential holography using phase conjugate reflection.

V. OBJECTIVES FOR THE COMING PERIOD

The objectives for the third year of this program, as originally planned, are to test the experimental apparatus and the tunable grating technique, first with the trial sample of IR-140 dye. We will then proceed to study other systems of significant scientific interest, including particularly semiconductor samples.

JSEP Sponsored Publications

1. A.E. Siegman, "Dynamic Interferometry and Differential Holography of Irregular Phase Objects Using Phase Conjugate Reflection," Optics Commun. 31, 257-258 (December 1979).
2. Rick Trebino and A.E. Siegman, "Phase Conjugate Reflection at Arbitrary Angles Using TEM_{00} Pump Beams," Optics Commun. 32(1), 1-4 (January 1980).
3. Wolfram Schmid, "Pulse-Stretching in a Q-Switched Nd:YAG Laser," in press.

Unit 6

A VUV AND SOFT X-RAY LIGHT SOURCE

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The spontaneous anti-Stokes VUV light source was proposed by Harris[6.1] in 1977 and first demonstrated by Zych, et al.[6.2] in 1978, and is a convenient technique for generating intense, narrowband, incoherent VUV radiation. The practicality of this source was demonstrated by Falcone, et al.[6.3] who used it as a tunable spectroscopic source to measure the isotopic shift, and absolute energies, of the ^{3}He and ^{4}He 1s2s $^1S_0$ states with a resolution of 60 μeV. This represented the first direct measurement of the isotopic shift and illustrated the potential of this technique for performing high-resolution VUV spectroscopy without the limitations of traditional VUV apparatus: the lack of bright sources, and the low efficiency and resolution of VUV spectrometers.

Falcone, et al. in essence performed an emission spectroscopy experiment using the anti-Stokes source. The goal of this project is to develop this source and to apply it to absorption spectroscopy of high lying atomic levels. The practical requirement is to produce a tunable source of high intensity which has an overwhelming majority of its energy in a narrow bandwidth, thus eliminating the need for a (lossy) VUV spectrometer.

[6.1] S. E. Harris, Appl. Phys. Lett. <u>31</u>, 498 (1977).
[6.2] L. J. Zych, et al., Phys. Rev. Lett. <u>40</u>, 1493 (1978).
[6.3] R. W. Falcone, et al., Optics Lett. <u>3</u>, 162 (1978).

A schematic of the source and its energy level diagram are shown in Fig. 6.1. The tunable, visible pump laser illuminates a length L of a He discharge. The anti-Stokes generation process is merely a scattering process; a fraction of the incident photon flux is scattered at the tunable sum frequency $\omega_{1s2s} + \omega_p$ into 4π steradians. The number of generated VUV photons is

$$n_{VUV} = n_{pump} \frac{d\sigma}{d\Omega} N_{1s2s} L$$

where n_{pump} is the number of incident pump photons, N_{1s2s} is the He 1s2s metastable density, $d\sigma/d\Omega$ is the differential cross section for anti-Stokes scattering, and L is the interaction length. The fraction of the generated photons which are actually used in a particular experiment will depend on the effective solid angle $\Delta\Omega$.

The differential scattering cross section depends strongly on the frequency of the applied pump wave, becoming very large when the VUV frequency approaches a resonance line. Initially, we proposed to pump with radiation in the range of 5300 Å and to scatter off the 1s2s $^1S_0$ He level excited by a dc discharge. The critical parameter of the source is the ratio of the anti-Stokes light to the background He resonance line radiation at 584 Å. Therefore, we have been investigating the optimization of the ratio of the anti-Stokes light to the background radiation using different discharge geometries to maximize N_{1s2s} , L , and the collection angle $\Delta\Omega$. We have found that a hollow cathode discharge and a positive column discharge are comparable in these respects.

We have measured this ratio using a flashlamp pumped dye laser which provides peak powers of a few kW as our pump source (see Fig. 6.2). The anti-Stokes light is seen superimposed on the background radiation over

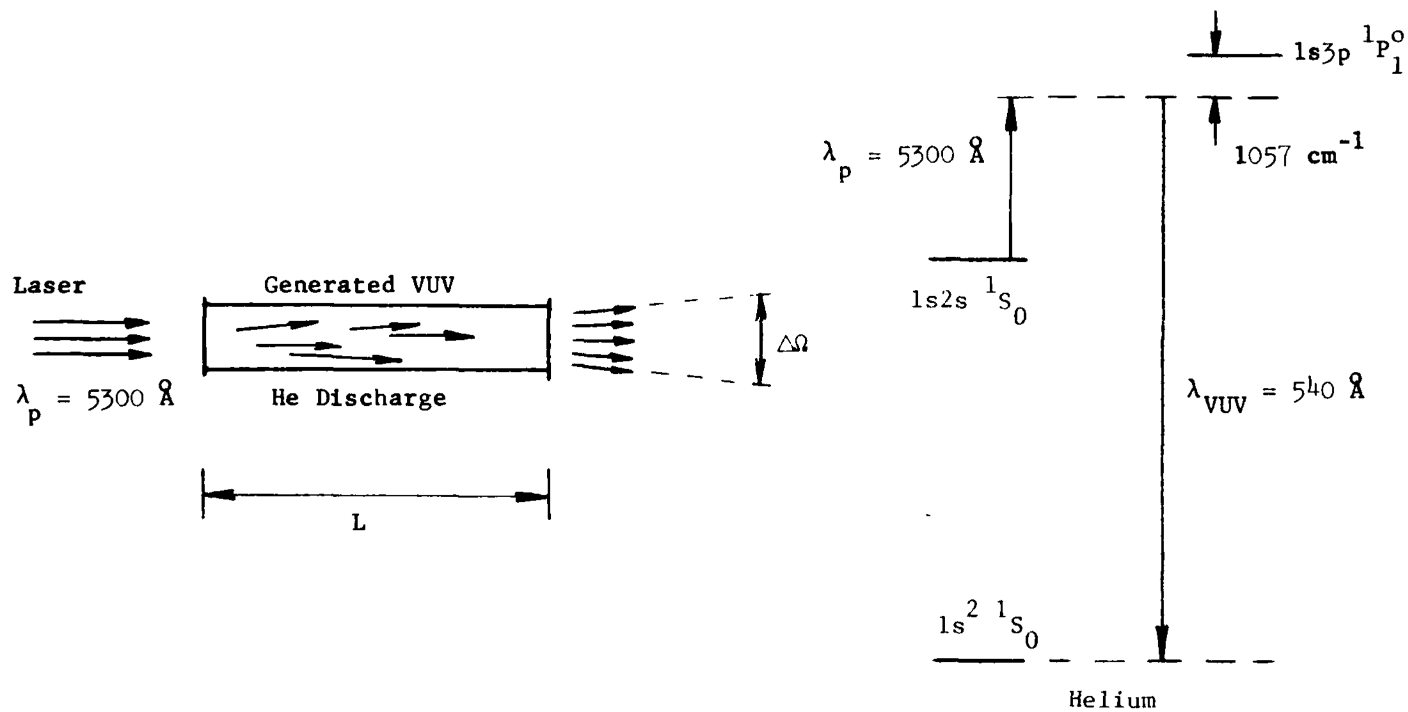

Fig. 6.1--He anti-Stokes VUV source.

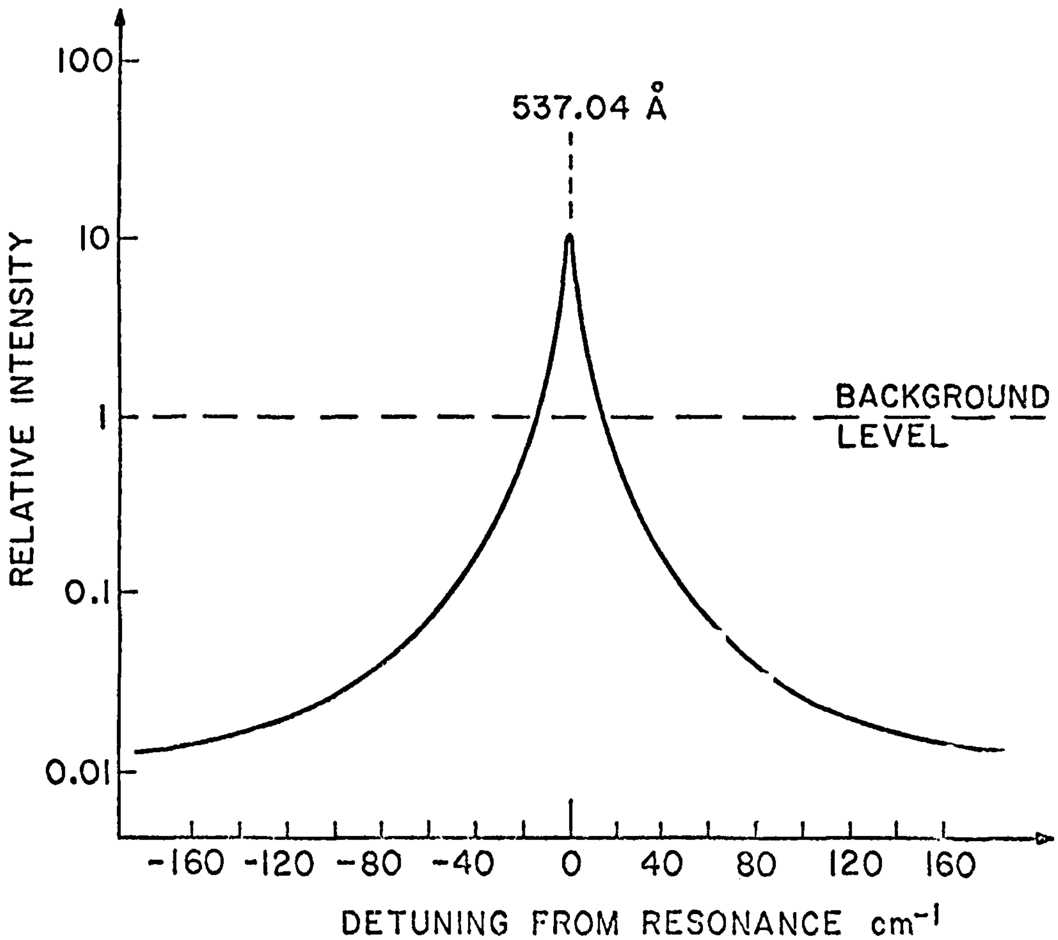

Fig. 6.2--Anti-Stokes brightness vs. pump laser detuning from resonance.

the range shown in the figure. Outside of this range the fluctuations of the background exceed the anti-Stokes intensity, making its observation impossible. However, we will be using a Nd:YAG system capable of producing MW peak powers which would allow observation of the generated anti-Stokes light over the entire range of available dye lasers (~ 50,000 cm^{-1}). In order to use this laser we have developed a detector with a high work function cathode which will not detect scattered visible laser radiation (at high laser powers this radiation can be comparable to the anti-Stokes light).

As a preliminary test of the Nd:YAG system we have used its second harmonic (5320 Å) at a peak power of 5 MW as our pump laser. This corresponds to a detuning of 1100 cm^{-1} (3 Å) from the resonance at 537.04 Å. The result was an observed anti-Stokes signal five times brighter than the background radiation. We believe this is confirmation that the source will be useful over the broad tuning range of available dyes.

The bandwidth of the generated anti-Stokes light is equal to the convolution of the pump laser bandwidth and the Doppler width of the metastable storage state. In our case this is only a few cm^{-1}, making the resolution and spectral brightness of the device much better than conventional laboratory sources. In the future we propose using this technique to measure the linewidth of the innershell excitation of K $3p^5 4s5s$. An energy level diagram is shown in Fig. 6.3 and an experimental schematic is shown in Fig. 6.4. There are good theoretical grounds for believing that the linewidth is relatively narrow, and thus, that the lifetime may be long enough so that it can be used in a VUV laser. To date, this linewidth has not been resolved. Generally, the linewidths of innershell excitations are very large because they are

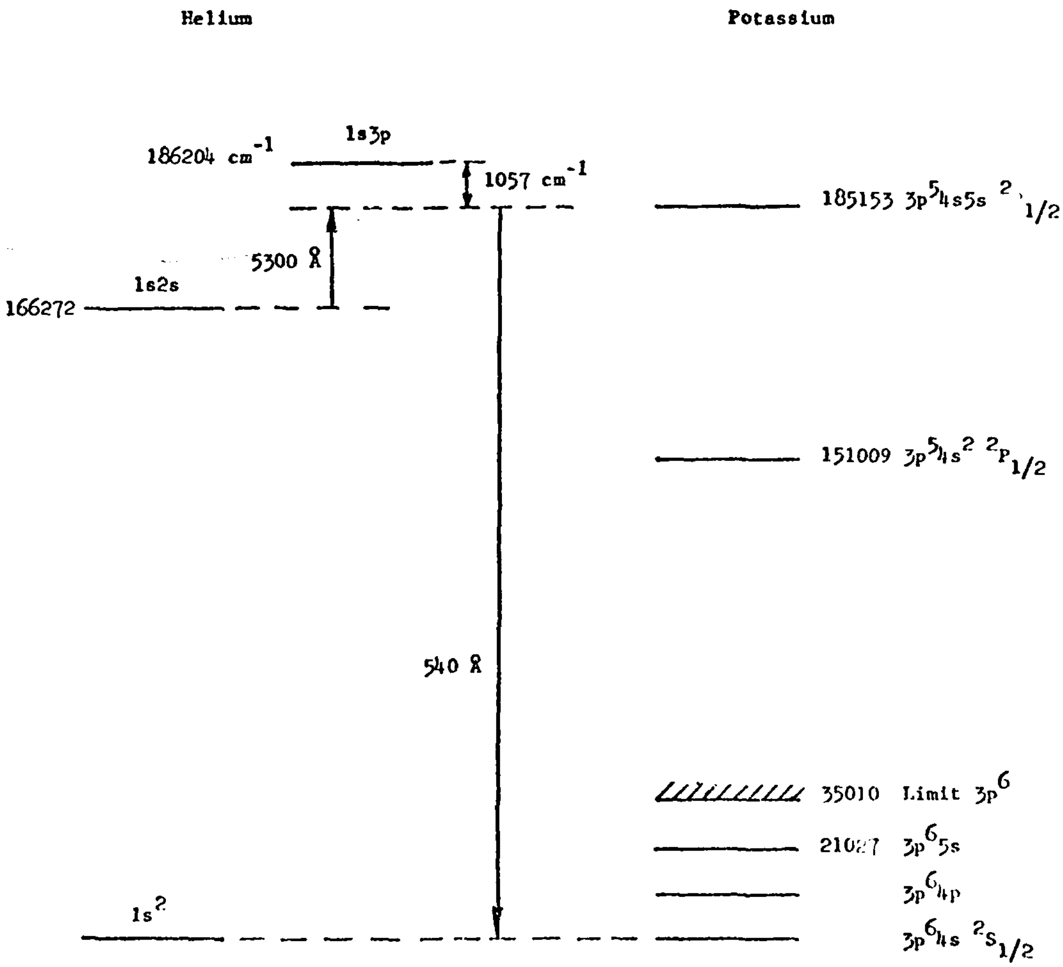

Fig. 6.3--Energy level diagram for spectroscopic studies of potassium autoionizing lines using the helium anti-Stokes VUV source.

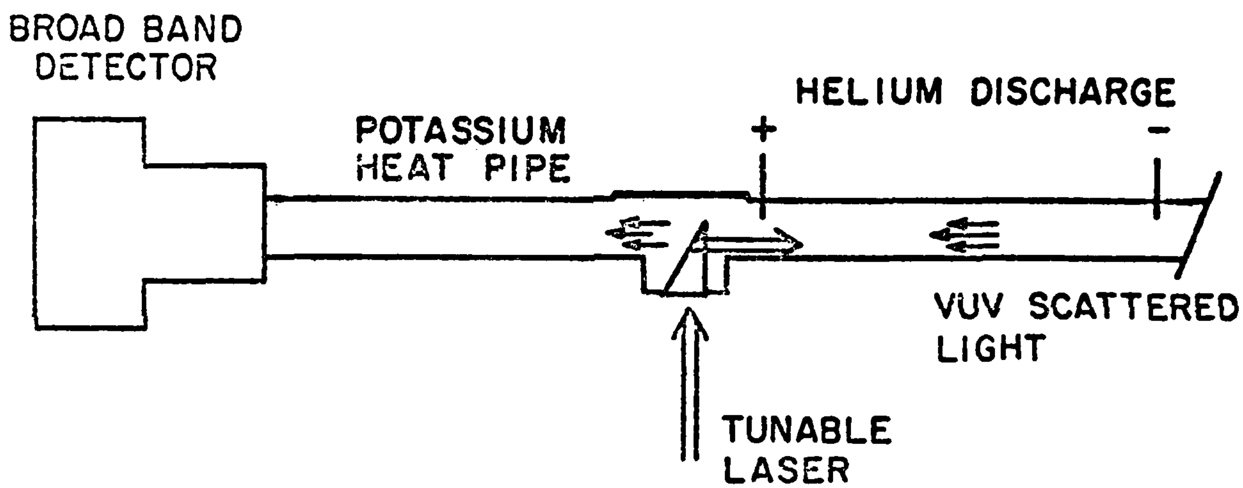

Fig. 6.4--VUV anti-Stokes spectroscopy in potassium.

prone to Auger or "autoionizing" decay. This very fast decay occurs when one electron drops into the closed innershell and ionizes the other electron. We plan to investigate a number of autoionizing lines in K, as well as in other alkali metals.

We note that this source of tunable, intense, incoherent VUV light has a number of other possible applications: photolithographic fabrication of microstructures; the analysis of surface composition and properties, including catalytic surfaces; and the testing and evaluation of the compatibility of materials and components in a high VUV flux environment.

REPORTS AND PUBLICATIONS OF THE

EDWARD L. GINZTON LABORATORY FACULTY AND STAFF

G.L. No.	Report	Contract
2950	Staff, "Annual Progress Report," for the period 1 April 1978 through 31 March 1979 (April 1979).	N00014-75-C-0632
2951	Staff, "Acoustic Techniques for Measuring Stress Regions in Materials," 40th Monthly Report for period 1 - 31 March 1979 (April 1979).	EPRI RP609-1
2952	NUMBER VOIDED	
2953	Staff, "Laser Physics and Laser Techniques," Annual Technical Report for the period 1 January - 31 December 1978 (April 1979).	F49620-77-C-0092
2954	J.C. White, "Laser Induced Collisions," Internal Memorandum and Special Research Report (April 1979).	F19628-77-C-0072
2955	J.E.M. Goldsmith, "High Resolution Spectroscopy of the Hydrogen Balmer-Alpha Line," Internal Memorandum and Special Research Report (June 1979).	NSF PHY77-09687 and N00014-78-C-0403
2956	Staff, "Acoustic Microscopy for Nondestructive Evaluation of Materials," Semiannual Technical Report for the period 1 August 1978 - 31 January 1979.	F49620-78-C-0098
2957	Staff, "Acoustically Scanned Optical Imaging Devices," Management Report for the period 1 January - 31 March 1979 (April 1979).	N00014-76-C-0129
2958	Staff, "Acoustic Microscopy for Nondestructive Evaluation of Materials," R & D Status Report covering the periods 1 August - 31 October 1978 and 1 November 1978 - 31 January 1979 (April 1979).	F49620-78-C-0098
2959	Staff, "Acoustic Microscopy for Nondestructive Evaluation of Materials," R & D Status Report covering the period 1 February - 30 April 1979 (April 1979).	F49620-78-C-0098

G.L. No.	Report	Contract
2960	J.E.M. Goldsmith, E.W. Weber, F.V. Kowalski, and A.L. Schawlow, "Precision Interferometer Calibration Technique for Wavelength Measurements: Iodine Wavelengths at 633 nm and H_α," Preprint (April 1979). <u>Also</u>: Published in Applied Optics, Vol. 18, 1983-1987 (June 15, 1979).	NSF PHY77-09687
2961	Staff, "Quantitative Modeling of Flaw Responses in Eddy Current Testing," Sixth Monthly Report for the period 15 March - 15 April 1979 (April 1979).	EPRI RP1395-3
2962	R.H. Hammond, B.E. Jacobson, T.H. Geballe, J. Talvacchio, J.R. Salem, H.C. Pohl, and A.I. Braginski, "Studies of Electron Beam Coevaporated Nb_3Sn Composites: Critical Current and Microstructure," Reprint from IEEE Trans. on Magnetics, Vol. MAG-15, No. 1, 619-622 (January 1979).	
2963	W.R. Trutna, Y.K. Park, and R.L. Byer, "The Dependence of Raman Gain on Pump Laser Bandwidth," Preprint (May 1979). <u>Also</u>: Published in IEEE J. Quant. Elect. Vol. QE-15, No. 7, 648-655 (July 1979).	F49620-77-C-0092
2964	A. Atalar, "Modulation Transfer Function for the Acoustic Microscope," Preprint (May 1979). <u>Also</u>: Published in Electronics Letters, Vol. 15, No. 11, 321-323 (24 May 1979).	F49620-78-C-0098
2965	R.N. Johnston, A. Atalar, J. Heiserman, V. Jipson, and C.F. Quate, "Acoustic Microscopy: Resolution of Subcellular Detail," Preprint (May 1979). <u>Also</u>: Published in Proceedings of the National Academy of Sciences USA, Volume 76, No. 7, 3325-3329 (July 1979).	NIH 1 R01 GM25826-01

G.L. No.	Report	Contract
2966	V.B. Jipson, "Acoustic Microscopy of Interior Planes," Preprint (May 1979). Also: Published in Applied Physics Letters, Vol. 35(5), 385-387 (1 September 1979).	F49620-78-C-0098
2967	W.R. Green, M.D. Wright, J. Lukasik, J.F. Young, and S.E. Harris, "Observation of a Laser Induced Dipole-Quadrupole Collision," Preprint (May 1979). Also: Published in Optics Letters, Vol. 4, No. 9, 265-267 (September 1979).	N00014-78-C-0403 and F19628-77-C-0072
2968	H.C. Tuan, G.S. Kino, B.T. Khuri-Yakub, and A.R. Selfridge, "Edge-Bonded Surface Acoustic Wave Transducer Array," Preprint (May 1979). Also: Published in Applied Physics Letters, Vol. 35(4), 320-321 (15 August 1979).	RISC RI74-20773 and NSF ENG77-28528
2969	S.J. Poon, "The Attenuation of Magnetic Interaction in Amorphous Metals," Preprint (May 1979). Also: Published in Physical Review B, Vol. 21, No. 1, 343-346 (1 January 1980).	F49620-78-C-0009
2970	Staff, "Acoustic Techniques for Measuring Stress Regions in Materials," 41st Monthly Report for the period 1 - 30 April 1979 (May 1979).	EPRI RP609-1
2971	J.E.M. Goldsmith, A.I. Ferguson, J.E. Lawler, and A.L. Schawlow, "Doppler-Free Two-Photon Opto-Galvanic Spectroscopy," Preprint (May 1979). Also: Published in Optics Letters, Vol. 4, No. 8, 230-232 (August 1979).	NSF PHY77-09687 and N00014-78-C-0403
2972	P.A. Belanger, A. Hardy, and A.E. Siegman, "Resonant Modes of Optical Cavities with Phase-Conjugate Mirrors," Preprint (May 1979).	F49620-77-C-0092

G.L. No.	Report	Contract
2973	J.D. Fraser, "The Design of Efficient, Broadband Ultrasonic Transducers," Internal Memorandum and Special Research Report (May 1979).	NSF ENG77-28528
2974	Staff, "Quantitative Modeling of Flaw Responses in Eddy Current Testing," Seventh Monthly Report for the period 15 April - 15 May 1979 (June 1979).	EPRI RP1395-3
2975	S.E. Harris, J.F. Young, W.R. Green, R.W. Falcone, J. Lukasik, J.C. White, J.R. Willison, M.D. Wright, and G.A. Zdasiuk, "Laser Induced Collisional and Radiative Energy Transfer," Preprint (June 1979). To appear in Laser Spectroscopy IV (New York: Springer-Verlag, 1979).	N00014-78-C-0403 and F19628-77-C-0072
2976	Staff, "Research Studies on Radiative Collision Lasers," Quarterly Report No. 9, for the period 10 March - 9 June 1979 (June 1979).	F19628-77-C-0072
2977	W.R. Trutna, Jr., "Generation of 16 Micron Radiation Using Stimulated Rotational Raman Scattering in Hydrogen," Internal Memorandum and Special Research Report (June 1979).	F49620-77-C-0092
2978	A. Atalar, "A Physical Model for Acoustic Signatures," Preprint (June 1979). Also: Published in Journal of Applied Physics, Vol. 50(12), 8237-8239 (December 1979).	F49620-78-C-0098
2979	J.R. Salcedo and A.E. Siegman, "Laser Induced Photoacoustic Grating Effects in Molecular Crystals," Reprint from IEEE Journal of Quantum Electronics, Vol. QE-15, No. 4, 250-256 (April 1979).	F49620-77-C-0092
2980	V.B. Jipson, "Acoustic Microscopy at Optical Wavelengths," Internal Memorandum and Special Research Report (June 1979).	F49620-78-C-0098
2981	Staff, "Acoustic Techniques for Measuring Stress Regions in Materials," 42nd Monthly Report for the period 1 - 31 May 1979 (June 1979).	EPRI RP609-1

G.L. No.	Report	Contract
2982	V. Jipson and A. Atalar, "Image Restoration for the Acoustic Microscope," Preprint (June 1979.	F49620-78-C-0098
2983	D. Rugar, J. Heiserman, S. Minden, and C.F. Quate, "Acoustic Microscopy of Human Metaphase Chromosomes," Preprint (June 1979).	NIH 1 R01 GM25826-01 and N00014-77-C-0412
2984	Bing-Hui Yeh, "SH Wave Propagation on Corrugated Surfaces," Internal Memorandum (July 1979).	N00014-75-C-0632
2985	S-C Sheng, "Diffraction-Biased Unstable Ring Resonators with Possible Applications in Laser Gyroscopes," Preprint (July 1979). Also: Published in IEEE Journal of Quantum Electronics, Vol. QE-15, No. 9, 922-926 (September 1979).	F49620-77-C-0092
2986	Staff, "Quantitative Modeling of Flaw Responses in Eddy Current Testing," Eighth Monthly Report for the period 15 May - 15 June 1979 (July 1979).	EPRI RP1395-3
2987	G.S. Kino and C.S. DeSilets, "Design of Slotted Transducer Array with Matched Backing," Preprint (July 1979). Also: Published in Ultrasonic Imaging 1, 189-209 (1979).	RISC RI74-20773 and N00014-75-C-0632
2988	Staff, "Tunable Optical Sources," Semiannual Report No. 4 for the period 1 January - 30 June 1979 (July 1979).	DAAG29-77-G-0221
2989	C.F. Quate, "Acoustic Microscopy," Preprint (July 1979). Also: Published in Scientific American, Vol. 241, No. 4, 62-70 (October 1979).	NIH 1 R01 GM25826-01 and F49620-78-C-0098
2990	Staff, "Significant Scientific Accomplishments and Technology Transition Reports," (July 1979).	N00014-75-C-0632

G.L. No.	Report	Contract
2991	G.S. Kino, "Nondestructive Evaluation," Preprint (August 1979). Also: Published in Science, Vol. 206, 173-180 (12 October 1979).	EPRI RP609-1, N00014-78-C-0283, NSF ENG77-28528 N00014-75-C-0632, RISC RI74-20773, NSF DMK76-00726(CMR)
2992	N.I. Koroteev, M. Endemann, and R.L. Byer, "Resolved Structure Within the Broadband Vibrational Raman Line of Liquid H_2O Using Polarization CARS," Preprint (May 1979). Also: Published in Physical Letters 43(5), 5, 398-401 (30 July 1979).	NSF CHE76-21987
2993	Staff, "Film Synthesis and New Superconductors," Interim Scientific Report for the period 1 October 1977 - 30 September 1978 (August 1979).	F49620-78-C-0009
2994	Staff, "Quantitative Modeling of Flaw Responses in Eddy Current Testing," Ninth Monthly Report for the period 15 June - 15 July 1979 (July 1979).	EPRI RP 1395-3
2995	S. Ayter and B.A. Auld, "On the Resonances of Surface Breaking Cracks," Preprint (July 1979). To be presented at the Review of Progress in Quantitative NDE at La Jolla, California.	RISC RI77-70946
2996	Staff, "Film Synthesis and New Superconductors," Interim Technical Report for the period 1 October 1978 - 31 March 1979.	F49620-78-C-0009
2997	Staff, "Film Synthesis and New Superconductors," Interim Technical Report for the period 1 April - 30 September 1979 (September 1979).	F49620-78-C-0009
2998	B.A. Auld, A. Ezekiel, D. Pettibone, and D.K. Winslow, "Surface Flaw Detection with Ferromagnetic Resonance Probes," Preprint (August 1979). Presented at the Review of Progress in Quantitative NDE held at La Jolla, California.	RISC 77-70946

G.L. No.	Report	Contract
2999	B. Budiansky, D.C. Drucker, G.S. Kino and J.R. Rice, "Pressure Sensitivity of a Clad Optical Fiber," Preprint (June 1979). Also: Published in Applied Optics, Vol. 18, pp. 4085-4088 (15 December 1979).	University of Michigan
3000	D. Behar, G.S. Kino, J.E. Bowers, and H. Olaisen, "The Storage Correlator as an Adaptive Inverse Filter," Preprint (August 1979). Also: Published in Electronics Letters, Vol. 16, No. 4, 130-131 (14 February 1980).	N00014-76-C-0129
3001	Staff, "Acoustic Techniques for Measuring Stress Regions in Materials," 43rd Monthly Report for the period 1 June - 31 July 1979 (August 1979).	EPRI RP609-1
3002	D. Behar, H. Olaisen, G.S. Kino, D. Corl, and P.M. Grant, "The Use of Programmable Filter for Inverse Filtering," Preprint (August 1979). To be published in Electronics Letters.	RISC RI74-20773
3003	J.H. Newton and J.F. Young, "Infrared Image Upconversion Using Two-Photon Resonant Optical Four-Wave Mixing in Alkali Metal Vapors," Preprint (April 1979). Also: Published in IEEE Journal of Quantum Electronics, Vol. QE-16, No. 3, 268-276 (March 1980).	DAAG29-77-G-0221
3004	Staff, "Acoustic Microscopy for Non-destructive Evaluation of Materials," R & D Status Report for the period 1 May - 31 July 1979 (August 1979).	F49620-78-C-0098
3005	R.D. Feldman, R.H. Hammond, and T.H. Geballe, "Electron Beam Co-evaporation of Superconducting A15 Nb-Si," Preprint (September 1979). Also: Published in Applied Physics Letters, Vol. 35(1), 818-821 (15 November 1979).	F49620-78-C-0009

G.L. No.	Report	Command
3006	Staff, "Acoustically Scanned Optical Imaging Devices," Semiannual Report No. 8, for the period 1 January — 30 June 1979 (August 1979).	N00014-76-C-0129
3007	Staff, "Quantitative Modeling of Flaw Responses in Eddy Current Testing," Tenth Monthly Report for the period 15 July — 15 August 1979 (August 1979).	EPRI RP1395-3
3008	Staff, "Acoustic Microscopy at Cryogenic Temperatures," Annual Summary Report for the period 1 July 1978 — 30 June 1979 (September 1979).	N00014-77-C-0412
3009	D.B. Ilic, G.S. Kino, and A.R. Selfridge, "Computer-Controlled System for Measuring Two-Dimensional Acoustic Velocity Fields," Preprint (September 1979). Also: Published in Review of Scientific Instruments, Vol. 50(12), 1527-1531 (December 1979).	NSF DMK76-00726(CMR) and AFOSR 78-3726
3010	Staff, "Investigation of Laser Dynamics, Modulation and Control by Means of Intra-Cavity Time Varying Perturbation," Semiannual Status Report No. 31, for the period 1 March — 31 August 1979 (September 1979).	NASA NGL-05-020-103
3011	Staff, "Studies on Lasers and Laser Devices," Semiannual Status Report No. 1 for the period 1 April - 30 September 1979 (September 1979).	NASA NSG-7619
3012	J. Tien, B. Khuri-Yakub, and G.S. Kino, "Acoustic Surface Wave Probing of Ceramics," Preprint (September 1799). Presented at the Review of Progress in Quantitative NDE, at La Jolla, California.	N00014-78-C-0283
3013	A.E. Siegman and Jean-Marc Heritier, "Analysis of the Mode-Locked and Intracavity Frequency-Doubled Nd:YAG Laser," Preprint (September 1979). Also: Published in IEEE Journal of Quantum Electronics, Vol. QE-16, No. 3, 324-335 (March 1980).	NASA NGL-05-020-103

G.L. No.	Report	Contract
3014	M.R. Beasley, "Progress Report on High-T_c Superconducting Devices," Reprint from Applications of Closed-Cycle Cryocoolers to Small Superconducting Devices, Proceedings of a Conference held at the National Bureau of Standards, Boulder, Colorado, 1977.	N00014-75-C-0632 and N00014-77-C-0439
3015	M.R. Beasley, "Improved Materials for Superconducting Electronics," Reprint from Future Trends in Superconductive Electronics, Proceedings of the AIP Conference, Charlottesville, Virginia, 1978.	N00014-77-C-0439 and N00014-75-C-0632
3016	R.B. van Dover, R.E. Howard, and M.R. Beasley, "Fabrication and Characterization of S-N-S Planar Microbridges," REPRINT from IEEE Trans. on Magnetics, Vol. MAG-15, No. 1, 574-577 (January 1979).	N00014-75-C-0632
3017	Staff, "Quantitative Modeling of Flaw Responses in Eddy Current Testing," Annual Summary for the period 1 October 1978 — 1 October 1979 (October 1979).	EPRI RP1395-3
3018	G.S. Kino, B.T. Khuri-Yakub, A. Selfridge, and H. Tuan, "Development of Transducers for NDE," Preprint (September 1979). Presented at the Review of Progress in Quantitative NDE held at La Jolla, California.	RISC RI74-20773, EPRI RP609-1, NSF ENG77-28528 N00014-78-C-0283
3019	G.S. Kino, "Zinc Oxide on Silicon Acoustoelectric Devices," Preprint (September 1979). Also: Published in 1979 IEEE Ultrasonics Symposium Proceedings, pp. 900-910.	N00014-76-C-0129 and N00014-75-C-0632
3020	E. Carome, K. Fesler, H.J. Shaw, D. Weinstein, and L.T. Zitelli, "PVF_2 Surface Wave Transducers," Preprint (September 1979). Also: Published in 1979 IEEE Ultrasonics Symposium Proceedings, pp. 641-644.	AFOSR 77-3386

G.L. No.	Report	Contract
3021	R.E. Teets, N.W. Carlson, and A.L. Schawlow, "Polarization Labeling Spectroscopy of NO_2," Preprint (September 1979). Also: Published in Journal of Molecular Spectroscopy, Vol. 78, 415-421 (1979).	NSF PHY77-09687
3022	D. Corl, G.S. Kino, D. Behar, H. Olaisen, and P. Titchener, "Digital Synthetic-Aperture Acoustic Imaging System," Preprint (September 1979). Presented at the Review of Progress in Quantitative NDE at La Jolla, California.	RISC RI74-20773
3023	Staff, "Acoustic Microscopy for Nondestructive Evaluation of Materials," Semiannual Technical Report for the period 1 February — 31 July 1979.	F49620-79-C-0098
3024	B.T. Khuri-Yakub, "Nondestructive Evaluation of Structural Ceramic Components," Preprint (September 1979). Also: Published in 1979 IEEE Ultrasonics Symposium Proceedings, pp. 309-320.	RISC RI74-20773 and N00014-78-C-0283
3025	Staff, "Research Studies on Radiative Collision Lasers," Quarterly Report No. 10 for the period 10 June — 9 September 1979 (September 1979).	F19628-77-C-0072
3026	S.E. Harris, "Proposal for a 207 Å Laser in Lithium," Preprint (September 1979). Also: Published in Optics Letters, Vol. 5, No. 1, 1-3 (January 1980).	N00014-78-C-0403
3027	M.P. Scott, D.M. Barnett, and D.B. Ilić, "The Nondestructive Determination of Residual Stress in Extruded Billets from Acoustoelastic Measurements," Preprint (September 1979). Also: Published in 1979 IEEE Ultrasonics Symposium Proceedings, pp. 265-268.	EPRI RP609-1 and NSF DMK76-00726(CMR)

G.L. No.	Report	Contract
3028	J.B. Green and B.T. Khuri-Yakub, "A 100 μm Beamwidth ZnO on Si Convolver," Preprint (September 1979). Also: Published in 1979 IEEE Ultrasonics Symposium Proceedings, pp. 911-912.	N00014-75-C-0632
3029	H.C. Tuan, A.R. Selfridge, J. Bowers, B.T. Khuri-Yakub, and G.S. Kino, "An Edge-Bonded Surface Acoustic Wave Transducer Array," Preprint (September 1979). Also: Published in 1979 IEEE Ultrasonics Symposium Proceedings, pp. 221-225.	RISC RI74-20773 and NSF ENG77-28528
3030	F. Yu, D.B. Ilić, B.T. Khuri-Yakub, and G.S. Kino, "Unipolar Transducers," Preprint (September 1979). Also: Published in 1979 IEEE Ultrasonics Symposium Proceedings, pp. 284-288.	EPRI RP609-1
3031	N. Grayeli, D.B. Ilić, F. Stanke, C.H. Chou, and J.C. Shyne, "Studies of Steel Microstructure by Acoustical Methods," Preprint (September 1979). Also: Published in 1979 IEEE Ultrasonics Symposium Proceedings, pp. 273-277.	AFOSR 78-3726
3032	D.B. Ilić, G.S. Kino, A.R. Selfridge, and F.E. Stanke, "Computer-Controlled System for Measuring Two-Dimensional Acoustic Velocity Fields," Preprint (September 1979). Also: Published in 1979 IEEE Ultrasonics Symposium Proceedings, pp. 269-272.	EPRI RP609-1, NSF DMK76-00726(CMR), AFOSR 78-3726
3033	N. Grayeli, D.B. Ilić, F. Stanke, G.S. Kino, and J.C. Shyne, "Acoustic Measurement of Microstructures in Steels," Preprint (September 1979). Presented at the Review of Progress in Quantitative NDE, held at La Jolla, California.	AFOSR 78-3726

G.L. No.	Report	Contract
3034	C.H. Chou, B.T. Khuri-Yakub, K. Liang, and G.S. Kino, "High-Frequency Bulk Wave Measurements of Structural Ceramics," Preprint (September 1979). Presented at the Review of Progress in Quantitative NDE, held at La Jolla, California.	RISC RI74-20773
3035	B.A. Auld, D.W. Pettibone, J.D. Plummer, and R.G. Swartz, "An Electronically Addressed Bulk Acoustic Wave Fourier Transform Device," Preprint (September 1979). Also: Published in 1979 IEEE Ultrasonics Symposium Proceedings, pp. 184-188.	AFOSR 76-3059
3036	B.A. Auld and D.K. Winslow, "Microwave Eddy Current Experiments with Ferromagnetic Resonance Probes," Preprint (October 1979). Presented at the Symposium on Eddy Current Characterization of Materials and Structures at the National Bureau of Standards, Gaithersburg, Maryland.	RISC 77-20946
3037	Staff, "Quantitative Modeling of Flaw Responses in Eddy Current Testing," Eleventh Monthly Report for the period 15 August — 15 September 1979 (September 1979).	EPRI RP1395-3
3038	A.E. Siegman, "Orthogonality Properties of Optical Resonator Eigenmodes," Preprint (October 1979). Also: Published in Optics Communications, Vol. 31, No. 3, 369-373 (December 1979).	F49620-77-C-0092
3039	Staff, "Acoustic Techniques for Measuring Stress Regions in Materials," 44th Monthly Report for the period 1 August — 30 September 1979 (October 1979).	EPRI RP609-1
3040	Staff, "Acoustic Techniques for Measuring Stress Regions in Materials," Annual Interim Report (October 1979).	EPRI RP609-1

G.L. No.	Report	Contract
3041	B.A. Auld and B-H Yeh, "Theory of Surface Skimming SH Wave Guidance by a Corrugated Surface," Preprint (October 1979). Also: Published in 1979 IEEE Ultrasonics Symposium Proceedings, pp. 786-790.	N00014-75-C-0632
3042	E. Carome, H.J. Shaw, D. Weinstein, and L.T. Zitelli, "PVF_2 Transducers for NDT," Preprint (October 1979). Also: Published in 1979 IEEE Ultrasonics Symposium Proceedings, pp. 346-349.	N00014-77-C-0582 and NSF DMR77-24222(CMR)
3043	K.N. Bates, E. Carome, K. Fesler, R.Y. Liu, and H.J. Shaw, "Digitally Controlled Electronically Scanned and Focused Ultrasonic Imaging System," Preprint (October 1979). Also: Published in 1979 IEEE Ultrasonics Symposium Proceedings, pp. 216-220.	EPRI RP609-1
3044	E.W. Weber, "Shift and Broadening of Resolved Hydrogen Balmer-α Fine-Structure Lines in Helium," Preprint (October 1979). Also: Published in Physical Review A, Vol. 20, No. 6, 2278-2286 (December 1979).	NSF PHY77-09687
3045	J. Kwo, R.H. Hammond, and T.H. Geballe, "Nb_3Al Thin Film Synthesis by Electron-Beam Coevaporation," Preprint (October 1979).	F49620-78-C-0009
3046	W.A. Harrison and S. Froyen, "Universal LCAO Parameters for d-State Solids," Preprint (October 1979). Also: Published in Physical Review A, Vol. 21, No. 8, 3214-3221 (15 April 1980).	NSF DMR77-21384

G.L. No.	Report	Contract
3047	W.R. Trutna and R.L. Byer, "Multiple-Pass Raman Gain Cell," Preprint (October 1979). Also: Published in Applied Optics, Vol. 19, No. 2, 301-312 (15 January 1980.	F49620-77-C-0092
3048	B.A. Auld, "Theoretical Characterization and Comparison of Resonant Probe Microwave Eddy Current Testing with Conventional Low Frequency Eddy Current Methods," Preprint (October 1979). Presented at the Symposium on Eddy Current Characterization of Materials and Structures held at The National Bureau of Standards, Gaithersburg, Maryland.	RISC 77-70946 and EPRI RP1395-3
3049	Staff, "Research on Nondestructive Testing," Final Report for the period 1 September 1978 through 31 August 1979 (October 1979).	AFOSR 78-3726
3050	J.A.G. Malherbe, "Impedance Matching and Equalization Tuning of Acoustic Transducer," Internal Memorandum (October 1979).	F49620-78-C-0098
3051	R. Trebino and A.E. Siegman, "Phase-Conjugate Reflection at Arbitrary Angles Using TEM_{00} Pump Beams," Preprint (November 1979). Also: Published in Optics Communications, Vol. 32, No. 1, 1-4 (January 1980).	N00014-75-C-0632
3052	W.E. Schmid, "Pulse Stretching in a Q-Switched Nd:YAG Laser," Preprint (November 1979).	N00014-75-C-0632
3053	Staff, "Quantitative Modeling of Flaw Responses in Eddy Current Testing," 12th Monthly Report for the period 15 September through 15 October 1979 (November 1979).	EPRI RP1395-3
3054	Staff, "Tunable Optical Sources," Final Report covering the period 1 September 1977 through 31 October 1979 (November 1979).	DAAG29-77-G-0221

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3055	R.W. Falcone and G.A. Zdasiuk, "Pair-Absorption-Pumped Barium Laser," Preprint (November 1979). Also: Published in Optics Letters, Vol. 5, No. 4, 155-157 (April 1980).	NASA NGL-05-020-103 and F49620-80-C-0023
3056	F. Yu, D.B. Ilić, B.T. Khuri-Yakub, and G.S. Kino, "Generation and Detection of Unipolar Stress Pulses," Preprint (November 1979). Also: Published in Applied Physics Letters, Vol. 36(7), 553-555 (1 April 1980).	EPRI RP609-1 and NSF ENG77-28528
3057	J. Hunter, R. King, G. Kino, D.M. Barnett, G. Herrmann, and D. Ilić, "The Use of Acoustoelastic Measurements to Characterize the Stress States in Cracked Solids," Preprint (November 1979).	AFOSR 78-3726, EPRI RP609-1, NSF DMK76-00726(CMR)
3058	W.T. Hill, III, R.A. Abreu, T.W. Hänsch, and A.L. Schawlow, "Sensitive Intracavity Absorption at Reduced Pressures," Preprint (November 1979). Also: Published in Optics Communications, Vol. 32, No. 1, 96-100 (January 1980).	NSF PHY77-09687
3059	Staff, "Acoustic Microscopy for Nondestructive Evaluation of Materials," R & D Status Report for the period 1 August - 31 October 1979 (November 1979).	F49620-78-C-0098
3060	S-C Sheng and A.E. Siegman, "Nonlinear Optical Calculations Using Fast Transform Methods: Second Harmonic Generation with Depletion and Diffraction," Preprint (November 1979). Also: Published in Physical Review A, Vol. 21, No. 2, 599-606 (February 1980).	F49620-77-C-0092

G.L. No.	Report	Contract
3061	Staff, "Elastic Domain Wall Waves in Ferroelectric Ceramics and Single Crystals," Progress Report (End-of-Year Letter) (December 1979).	N00014-79-C-0222
3062	J. Kwo, R.H. Hammond, and T.H. Geballe, "Nb_3Al Thin Film Synthesis by Electron-Beam Coevaporation," Preprint (December 1979). Also: Published in Journal of Applied Physics, Vol.	F49620-78-C-0009
3063	P.D. Corl and G.S. Kino, "A Real-Time Synthetic-Aperture Imaging System," Preprint (December 1979). Presented at the Acoustical Holography Conference, held at Houston, Texas.	RISC RI74-20773 and F49620-79-C-0217
3064	C.H. Chou, B.T. Khuri-Yakub, and G.S.Kino, "Transmission Imaging: Forward Scattering and Scatter Reconstruction," Preprint (December 1979). Presented at the Acoustical Holography Conference, held at Houston, Texas.	RISC RI74-20773
3065	Staff, "Quantitative Modeling of Flaw Responses in Eddy Current Testing," 13th Monthly Report for the period 15 October - 15 November 1979 (December 1979).	EPRI RP1395-3
3066	Staff, "Measurement of Surface Defects in Ceramics," End-of-the-Year Letter for 1979 (December 1979).	N00014-78-C-0283
3067	G.S. Kino, D.M. Barnett, N. Grayeli, G. Herrmann, J.B. Hunter, D.B. Ilić, G.C. Johnson, R.B. King, M.P. Scott, J.C. Shyne, and C.R. Steele, "Acoustic Measurements of Stress Fields and Microstructure," Preprint (December 1979). To be published in the Journal of Nondestructive Testing.	EPRI RP609-1, F49620-79-C-0217, NSF DMK76-00726(CMR)

G.L. No.	Report	Contract
3068	J.E. Bowers, G.S. Kino, D. Behar, and H. Olaisen, "Adaptive Deconvolution Using an ASW Storage Correlator," Preprint (December 1979).	N00014-76-C-0129
3069	K.L. Wang, J.H. Goll, and G.S. Kino, "Grating-Coupled Optical Imaging Using an Acoustoelectric Memory Correlator," Preprint (December 1979).	-------
3070	Staff, "Acoustic Techniques for Measuring Stress Regions in Materials," 45 Report for the period 1 October — 30 November 1979 (December 1979).	EPRI RP609-1
3071	D.E. Prober, R.E. Schwall, and M.R. Beasley, "Upper Critical Fields and Reduced Dimensionality of the Superconducting Layered Compounds," Preprint (December 1979). Also: Published in Physical Review B, Vol. 21, No. 7, 2717-2733 (1 April 1980).	NSF DMR75-04368
3072	A.E. Siegman, "Exact Cavity Equations for Lasers with Large Output Coupling," Preprint (December 1979). Also: Published in Applied Physics Letters, Vol. 36(6), 412-414 (15 March 1980).	F49620-77-C-0092
3073	Staff, "Quantitative Modeling of Flaw Responses in Eddy Current Testing," 14th Monthly Report for the period 15 November — 15 December 1979 (December 1979).	EPRI RP1395-3
3074	Staff, "Research Studies on Radiative Collision Lasers," Quarterly Report No. 11, for the period 10 September — 9 December 1979 (January 1980).	F19628-77-C-0072
3075	B.A. Auld, "Fundamentals of Ultrasonic Waves," Technical Report (January 1980).	RISC 77-70946

G.L. No.	Report	Contract
3076	Staff, "Elastic Domain Wall Waves in Ferroelectric Ceramics and Single Crystals," Annual Progress Report for the period 1 February 1979 — 31 January 1980 (January 1980).	N00014-79-C-0222
3077	Y.K. Park, G. Giuliani, and R.L. Byer, "Stable Single-Axial-Mode Operation of an Unstable-Resonator Nd:YAG Oscillator by Injection Locking," Preprint (January 1980). Also: Published in Optics Letters, Vol. 5, No. 3, 96-98 (March 1980).	F49620-77-C-0092
3078	Staff, "Processing of Optical Images with Optimally Controlled Acoustic Transducers," Final Technical Report (January 1980).	AFOSR 76-3059
3079	D.B. Kimhi and T.H. Geballe, "Superconducting Tunneling in the Amorphous Transition Metals Mo and Nb," Preprint (January 1980).	F49620-78-C-0009 and NSF-MRL Program (CMR)
3080	S.J. Poon, "Eliashberg Function in Amorphous Superconductors," Preprint (January 1980). Accepted for publication in Solid State Communications.	F49620-78-C-0009
3081	Shang-Yuan Ren and W.A. Harrison, "Semiconductor Properties Based Upon Universal LCAO Parameters," Preprint (January 1980).	NSF DMR77-21384
3082	Staff, "Acoustic Microscopy for Nondestructive Evaluation of Materials," R & D Status Report for the period 1 November 1979 — 31 January 1980 (January 1980).	F49620-78-C-0098
3083	Staff, "Acoustic Microscopy at Cryogenic Temperatures," Status Report for the period 1 July 1979 — 1 January 1980 (January 1980).	N00014-77-C-0412
3084	Abdullah Atalar, "A Backscattering Formula for Acoustic Transducers," Preprint (January 1980). Accepted for publication in the June 1980 issue of the Journal of Applied Physics.	F49620-78-C-0098

G.L. No.	Report	Contract
3085	D.A. Rudman and M.R. Beasley, "Oxidized Amorphous-Silicon Superconducting Tunnel Junction Barriers," Preprint (January 1980). Accepted for publication in Applied Physics Letters.	N00014-77-C-0439
3086	J.R. Willison, R.W. Falcone, J.C. Wang, J.F. Young, and S.E. Harris, "Emission Spectra of Core-Excited Even Parity ^2P States of Neutral Lithium," Preprint (February 1980).	N00014-78-C-0403
3087	Staff, "Quantitative Modeling of Flaw Responses in Eddy Current Testing," 15th Monthly Report for the period 15 December 1979 — 15 January 1980 (February 1980).	EPRI RP1395-3
3088	A.E. Siegman, "Dynamic Interferometry and Differential Holography of Irregular Phase Objects Using Phase Conjugate Reflection," Reprinted from Optics Communications, Vol. 31, No. 3, 257-258 (December 1979).	N00014-75-C-0632
3089	Staff, "Acoustically Scanned Optical Imaging Devices," Semiannual Report No. 8 for the period 1 July — 31 December 1979 (February 1980).	N00014-76-C-0129
3090	Staff, "Research Studies on Radiative Collision Lasers," Final Report for the period 10 March 1977 — 9 January 1980 (February 1980).	F19628-77-C-0072
3091	J.E. Bowers, B.T. Khuri-Yakub, and G.S. Kino, "Broadband, Efficient, Thin Film Sezawa Wave IDTs," Preprint (February 1980). Accepted for publication in Applied Physics Letters.	N00014-76-C-0129
3092	Staff, "Acoustic Techniques for Measuring Stress Regions in Materials," 46th Report for the period 1 December 1979 — 31 January 1980.	EPRI RP609-1
3093	Staff, "Laser Physics and Laser Techniques," Final Technical Report for the period 1 January 1977 — 31 December 1979 (February 1980).	F49620-77-C-0092

G.L. No.	Report	Contract
3094	Staff, "Research on New Approaches to Optical Systems for Inertial Rotation Sensing," Final Report for the period 1 October 1978 — 30 September 1979.	AFOSR 76-3070
3095	Staff, "Acoustic Microscopy for Non-destructive Evaluation of Materials," Semiannual Technical Report for the period 1 August 1979 — 31 January 1980 (February 1980).	F49620-79-C-0098
3096	W.A. Harrison, "Elementary Quantitative Theory of Chemical Bonding," Preprint (February 1980). To be published in Treatise on Structural Chemistry in Complex Solids (Academic Press, New York).	NSF DMR77-21384
3097	J. Heiserman, D. Rugar, and C.F. Quate, "Cryogenic Acoustic Microscopy," Preprint (February 1980). Accepted for publication in Journal of the Acoustical Society of America May 1980 issue.	N00014-77-C-0412
3098	R.A. Bergh, G. Kotler, and H.J. Shaw, "Single Mode Fiber Optic Directional Coupler," Preprint (February 1980). To appear in Electronics Letters.	N00014-75-C-0632
3099	S.T. Ruggiero, T.W. Barbee, Jr., and M.R. Beasley, "Superconductivity in Quasi-Two-Dimensional Layered Composites," Preprint (February 1980).	NSF DMR79-11117
3100	M.R. Beasley, "Advanced Superconducting Materials for Electronic Applications," Preprint (February 1980).	N00014-77-C-0439
3101	D.J. Jackson, E. Arimondo, J.E. Lawler, and T.W. Hänsch, "Infrared Optogalvanic Spectroscopy in the Helium Positive Column Using an F-Center Laser," Preprint (March 1980). Accepted for publication in Optics Communication.	NSF PHY77-09687 and N00014-78-C-0403
3102	Index for the year 1979.	--------

G.L. No.	Report	Contract
3103	Staff, "Quantitative Modeling of Flaw Responses in Eddy Current Testing," 16th Monthly Report for the period 15 January — 15 February 1980 (March 1980).	EPRI RP1395-3
3104	A.R. Selfridge, G.S. Kino, and B.T. Khuri-Yakub, "A Theory for the Radiation Pattern of a Narrow Strip Acoustic Transducer," Preprint (March 1980). Accepted for publication in the 1 July 1980 issue of Applied Physics Letters.	EPRI RP609-1 and F49620-79-C-0217
3105	C.H. Chou, K. Liang, B.T. Khuri-Yakub, and G.S. Kino, "Shear Wave Excitation in a Solid by Longitudinal Wave Contact Transducers," Preprint (March 1980).	NSF ENG77-28528
3106	S-C Sheng, "Studies of Laser Resonators and Beam Propagation Using Fast Transform Methods," Internal Memorandum and Special Research Report (March 1980).	F49620-77-C-0092
3107	C. Wieman and T.W. Hänsch, "Precision Measurement of the 1S Lamb Shift and of the 1S-2S Isotope Shift of Hydrogen and Deuterium," Preprint (March 1980). Accepted for publication in Physical Review A.	NSF PHY77-09687
3108	Staff, "Film Synthesis and New Superconductors," Interim Technical Report for the period 1 October 1979 — 31 March 1980.	F49620-78-C-0009
3109	Staff, "PVF_2 Transducers for Nondestructive Evaluation of Ceramics and Brittle Materials," Annual Report for the period 1 July 1978 — 30 June 1979.	AFOSR 77-3386
3110	R.B. van Dover, A. de Lozanne, R.E. Howard, W.L. McLean, and M.R. Beasley, "Refractory Superconductor S-N-S Microbridges," Preprint (March 1980).	N00014-75-C-0632

G.L. No.	Report	Contract
3111	A.E. Siegman, "A Prony Algorithm for Fitting Exponential Factors or Extracting Matrix Eigenvalues from a Sequence of Complex Numbers," Preprint (March 1980).	AFOSR 80-0145
3112	B.A. Auld and S. Ayter, "Measurement of Resonances of Surface Cracks," Interim Report for the period 1 October 1979 — February 1980 (March 1980).	RISC 77-70946

LABORATORY CONTRACT AND GRANT SUPPORT

(Edward L. Ginzton Laboratory)

SOURCE — CONTRACT-GRANT NO.	PRINCIPAL INVESTIGATORS	TITLE	EXPIRATION DATE AS OF 5/28/80
1. Air Force Office of Scientific Research			
F49620-78-C-0009	Geballe	Film Synthesis and New Superconductors	9/30/80
F49620-78-C-0098	Quate	Acoustic Microscopy for Nondestructive Evaluation of Materials	6/30/81
F49620-79-C-0217	Kino	Research on Nondestructive Evaluation	8/31/81
F49620-80-C-0023	Harris/Young	Research Studies on Radiative Collisional Processes	9/30/80
F49620-80-C-0040	Shaw/Chodorow	New Approaches to Optical Systems for Inertial Rotation Sensing	12/31/80
AFOSR-77-3336	Shaw	PVF_2 Transducers for Nondestructive Evaluation of Ceramics and Brittle Materials	6/30/80
AFOSR-80-0144	Byer	Laser Physics and Laser Spectroscopy	2/14/81
AFOSR-80-0145	Siegman	Laser Physics and Laser Techniques	1/31/81
2. Air Force Systems Command			
F33615-79-C-1789	Shaw/Chodorow	Fiber Ring Laser Gyro Amplifier	6/15/80
3. Army Research Office			
DAAG29-79-C-0181	Byer	Tunable Optical Sources and Nd:Glass Laser Research	8/31/80
4. Electric Power Research Institute			
EPRI RP609-1	Kino/Shaw	Acoustic Techniques for Measuring Stress Regions in Materials	6/30/82
EPRI RP1395-3	Auld	Quantitative Modeling of Flaw Responses in Eddy Current Testing	10/14/80
5. Industrial Contracts			
Anaconda Industries	Shaw	Research on Fiber Optic Directional Couplers	10/31/80

SOURCE — CONTRACT-GRANT NO.	PRINCIPAL INVESTIGATORS	TITLE	EXPIRATION DATE AS OF 5/28/80
6. **National Aeronautics and Space Administration**			
NGL-05-020-103	Harris/Siegman	Studies on Lasers and Laser Devices	3/31/80
NCC 2-50	Byer	Ultra High Resolution Molecular Beam CARS Spectroscopy With Applications to Planetary Molecules	12/31/80
NSG 2289	Byer	Applications of CARS Spectroscopy to Turbulence Measurements	12/31/80
NSG 7619	Harris/Siegman/Young	Studies on Lasers and Laser Devices	3/31/80
7. **National Institutes of Health**			
NIH 1-R01-GM25826-02	Quate	Acoustic Microscopy for Biomedical Applications	11/30/80
8. **National Science Foundation**			
NSF CHE79-12673	Byer	Molecular Beam CARS Spectroscopy	7/31/80
NSF DMR77-21384	Harris	Pseudopotential Methods in Physics	12/14/80
NSF DMR79-11117	Beasley	Electromagnetic Properties of Layered Superconducting Structures	6/30/80
NSF ECS 79-25811	Siegman	Cooling Water System (Equipment)	1/31/81
NSF ENG77-01119	Chodorow	Nonlinear Generation of Sound in the Scanning Acoustic Microscope	7/14/80
NSF ENG77-28528	Kino	Acoustic Wave Transducers	6/30/80
NSF ENG77-28541	Auld	Variational Methods for Acoustic Wave Scattering and Propagation in Solids	6/30/80
NSF PHY77-09687	Schawlow/Hansch	Spectroscopy and Quantum Electronics	5/31/80
NSF PHY78-23532	Schawlow	Precision Optical Wavemeters	2/14/81
9. **Navy**			
N00014-75-C-0632	Chodorow	Optical and Acoustic Wave Research (JSEP)	3/31/81
N00014-76-C-0129	Kino	Acoustical Scanning of Optical Images	9/30/80
N00014-77-C-0412	Quate	Acoustic Microscopy at Cryogenic Temperatures	6/30/82
N00014-77-C-0439	Beasley	Superconducting Tunneling and Tunnel Applications in High TC A15 Superconductors	4/30/80

SOURCE — CONTRACT-GRANT NO.	PRINCIPAL INVESTIGATORS	TITLE	EXPIRATION DATE AS OF 5/28/80
9. Navy (Continued)			
N00014-77-C-0582	Shaw	Piezoelectric PVF_2 Polymer Films and Devices	7/31/80
N00014-79-C-0222	Auld	Elastic Domain Wall Waves in Ferroelectric Ceramics and Single Crystals	1/31/82
N00014-78-C-0283	Kino	Measurements of Surface Defects in Ceramics	2/28/81
N00014-78-C-0403	Schawlow/Harris	Advanced Laser Source Research	3/31/81
N00014-79-C-0618	Beasley/Geballe	RF Properties of Superconducting A-15 Compounds	12/19/80
10. Subcontracts			
Lawrence Livermore Laboratory LLL 3488009	Byer	Define Algorithms Appropriate to a High Laser Wavelength Measuring Instrument	3/15/81
Rockwell International Science Center RISC BO-F01246-3	Kino	Development of High Frequency Techniques for Ceramics and Other Materials	9/30/80
Rockwell International Science Center RISC BO-F01243-3	Auld	Methods for Detection and Characterization of Surface Flaws in Materials	9/30/80
11. Swiss Institute for Nuclear Research			
SIN PO# 098533	Byer	Prototype of 60,000 Å Nd:Glass Laser	5/31/80

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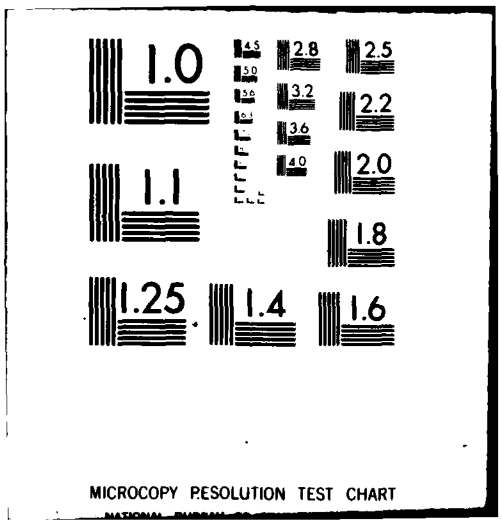
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Superconductivity	Acoustic Wave Interactions with Ferroic Materials	Weak Link Josephson Junctions and Circuits
Acoustics		
Surface Waves	Ultrafast Phenomena Measurement	Acoustic Surface Wave Scanning
Optical Image Scanning	VUV and Soft X-Ray Light Sources	
Fiber Optics	Laser Spectroscopy	p-n Junctions Addressing
Signal Processing	High T_c Materials	Adaptive Antennas

20. ABSTRACT (Continue on reverse side if necessary and identify by Block no.)

This report summarizes the research progress and activity on Joint Services Electronics Program Contract N00014-75-C-0632 for the period 1 April 1979 through 31 March 1980. Specific Projects are: (1) High-T_c Superconducting Weak-Link Josephson Junctions and Circuits (M.R. Beasley); (2) Acoustic Surface Wave Scanning of Optical Images (G.S. Kino); (3) Research on Fiber Optic Interactions with Application to High Speed Signal Processing (H.J. Shaw); (4) Nonlinear Interactions of Acoustic Waves with Domains in Ferroic Materials (B.A. Auld); (5) Measurement of Ultrafast Physical Phenomena (A.E. Siegman); (6) A VUV and Soft X-Ray Light Source (S.E. Harris and J.F. Young).

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